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READABLE SCHOOL PHYSICS

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PREFACE

THIS book is an attempt to humanise Elementary Physics without popularising it. The writer has long felt that the atmosphere of the physical laboratory is, to a certain extent, artificial: pupils do not realise that they are studying nature. In some respects, this cannot be avoided, for the bulk of a first year's course in Physics is devoted to acquiring proficiency in the use of apparatus, and accuracy in measurement. Although this is so, the human element may profitably be introduced, and the first principles of scientific method inculcated by the judicious use of historical references, and by practical applications of the principles "discovered" by the pupils. It often happens, too, that, in the maze of experimental detail, and as a result of preoccupation with unfamiliar pieces of apparatus, the pupils lose sight of the broad principles they are studying. Periodical revision lessons, of course, tend to correct this fault, but a permanent record to which reference may be made at any time is, in the writer's opinion, absolutely essential.

This is the *raison d'être* of the book, which, it is thought, fills a gap in the list of available books on the subject. Theory has been given the main prominence. Experi-

ments have not been described unless to elucidate principles ; it is in no respect a laboratory manual. References to the makers of scientific history are frequent, and connection with the pupil's own experience is established as often as possible. It is suggested that the book is suitable for home reading concurrently with the practical work in the laboratory ; at the end of a set of experiments, the corresponding chapter in the book could be read. In this way the work would be co-ordinated and ideas would take definite shape.

Acting on the advice of Messrs Bell's scientific adviser, the author has included two chapters on Surveying at the end of Part I.

I am much indebted to my friends Mr. R. B. Lyall, M.A., and Mr. N. M. Johnson, B.Sc., for valuable criticisms and suggestions. Mr. Wm. Douglas, M.A., kindly read the proofs, and made several useful suggestions. Thanks are also due to Mr. C. Baker, the well-known maker of scientific apparatus (High Holborn, W.C.), for allowing me to illustrate various instruments.

J. A. C.

PREFACE TO THE THIRD EDITION

SOME minor alterations have been made in the text for this edition, and, at the request of several teachers, lists of questions and numerical exercises have been added at the end of the book. In Chapter XVII. a method of finding the coefficient of apparent expansion of a liquid is now described which, as far as the author knows, does not appear in this form in any text-book, and which is more easily understood by young pupils than the methods usually employed.

Several teachers have been good enough to express their opinions of the book to the publishers or to the author, and their friendly criticism is much appreciated. Among the suggestions made was that the inclusion of chapters on Light or Magnetism would add to the usefulness of the book, but as these subjects are not universally taught in the lower classes it has not been thought advisable to act on the suggestions which would add to the price of the book without, in most cases, bringing any additional advantage.

J. A. C.

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PART I.—HYDROSTATICS

CHAPTER I

INTRODUCTION

What is a Laboratory?

When you enter a physical laboratory for the first time, your impression of it probably is that it is somewhat like a workshop with its benches fitted with gas and water supply, and its instruments arranged round the walls of the room all ready for use. Well, that is exactly what a laboratory is: it is a workshop—in fact, to those of you who know a little Latin its very name indicates its nature. It is a workshop, however, not in the ordinary sense of the word, that is, a place where things are made that will afterwards be sold. The work that is done in a laboratory is not the construction of useful articles; it is the discovery and the application of the wonderful laws of nature, the study, in certain aspects, of the world on which we live. Nevertheless, a laboratory is really a workshop, or, to get away from the idea of a shop, we might call it a workroom, for it is a room where work is done. But, you might say, any room in the school could be called a workroom in the same sense. Quite true; but the difference between the laboratory and, say, the history classroom is that, in the latter, you read in books and learn from your teacher

about what men and nations have done in the past, why events happened as they did, and so on, whereas in the laboratory you do things for yourself, find out by your own effort interesting facts about the world without having to rely entirely on what other people say.

What is Science?

Almost since man appeared upon the earth, he has been asking Why? His curiosity has been aroused by all the various events that occur in nature, and he has been seeking the reasons for them. Gradually, very slowly at first, by investigation and experiment, he has built up a vast amount of knowledge, so vast that now no one mind can possibly contain it all. It has been a very long process, and it is still going on—every year men are finding out something they did not know before. Now all those facts that have been brought together, studied carefully, and organised are what we call science. Seeing that it has taken thousands and thousands of years to find out all that is now known about the world and the whole universe, you who are just beginning to study the subject cannot hope to learn all about it in the few years you spend at school, but you will find out some fundamental principles that are the basis of all science, and you will then be able to take an intelligent interest in what goes on around you, and be in a position to find out more for yourselves.

Measurement the Basis of all Science.

One of the reasons why it took so long to come to our present state of knowledge is that the ancient scientists (or philosophers, as they were called) ascribed a great many of the wonders of nature to the action of their gods. Instead of inquiring into the causes of rain, wind, thunderstorm, etc., they asked *who* it was that sent rain from the skies, *who* made the winds blow, *whose* anger was kindled

when it thundered. When they had named the various gods who were responsible for those happenings, they were perfectly satisfied. It is obvious that there would not be much progress while that state of mind prevailed. When gradually those superstitions were laid aside, they fell into yet another error: they did not do enough measuring. Now measurement, as you will soon see, lies at the very root of all science, and your first term will be devoted almost entirely to measurement. That does not sound very interesting, does it? When measurement is spoken of, you immediately think of a ruler; but there are many other measurements besides that of length to be taken into account—measurements which you will find it interesting to make. This part of science which deals with measurement is called Physics. Science is divided up into a great many departments; for example, chemistry, astronomy, botany, geology, to mention only a few, are all branches of science. Physics, itself a branch of science, is also divided up into sub-departments such as heat, light, and electricity. All, however, depend ultimately on measurement. No substantial progress was made in any branch of science until the special measuring instruments which that branch required were constructed. In the same way, before you can make any progress, you must learn how to use the instruments that have been provided for you.

CHAPTER II

UNITS OF MEASUREMENT

Ancient Units.

Before beginning to measure for yourselves, it will be interesting to glance briefly at some of the measures used in olden times. In the Old Testament the word "cubit" is mentioned very often; it was one of the measures of length used at that time. The dimensions of Solomon's Temple, for instance, are all given in cubits. It was the distance from a man's elbow to the tip of his middle finger. In our units, it would be about $1\frac{1}{2}$ feet. For shorter distances, the "digit" was used. It was the width of the finger, and would be about three-quarters of an inch. Another measure was the "palm," which, as its name indicates, was the breadth of the palm of the hand. It would therefore be equal to four digits, or about 3 inches. Notice that these measures were all taken from parts of the human body, and therefore they were not always the same, though the variation would not be very great. If such measures were in use to-day, they would cause a great deal of confusion and annoyance, as no doubt they did when they were actually in use. If ribbon were sold by the cubit, then a lady would buy her ribbon in a shop where the salesman had a very long arm, for she would get the biggest bargain there. It would also lead to all kinds of dishonesty in trading which would be difficult to detect. A state of affairs similar to this was in existence in England at a period much more recent than Biblical times. Each county in England used to have a different

measure for wheat, and even in the same county measures were not always uniform. Those differences were, of course, ridiculous and confusing, but they lasted a long time. It was not till 1878 that an Act of Parliament put an end to all the local measures, and established imperial standards.

Origin of our Units.

The origin of our system of weights was the grain of wheat: 32 grains of wheat, which had to be taken from the middle of the ear and well dried, made 1 pennyweight; 20 pennyweights were called an ounce, and 20 ounces 1 pound. Several changes were made in the pound, until, in the reign of Henry VII., the pound as we know it was made legal.

The original basis of length was also the grain: 3 grains of barley-corn, well dried and placed end to end, were taken as 1 inch The modern yard is sometimes said to have been the length of the arm of King Henry I., but that is not strictly true. During that king's reign, it was shown to be necessary to fix a definite standard of length, and the king's arm was taken as that standard, but it was not called a yard; it was called an ell. It was in the year 1878 that the standard yard was fixed as the distance between two lines marked on a certain brass rod which is kept in London. It is not quite certain why this particular length was fixed on, but it was probably made for convenience thirty-six times the length of an inch, the inch being fixed as before as the length of 3 grains of corn placed end to end. The Romans had long ago used a measure of length called a foot, because it was very nearly the length of the average man's foot. It was found that the Roman foot was nearly one-third of the length of the new yard, and so, for simplicity, the yard was divided into three equal parts, each called a foot.

The origins of the other measures of length—the pole, the furlong, the chain, etc.—are very interesting. When ploughing was done by oxen instead of by horses, it was found convenient to make the fields of such a length that the oxen could go from one end to the other without having to be rested. This distance was usually referred to as a furrow long, and it is easy to see how that came to be shortened to furlong. We know it now simply as an eighth of a mile, but it came into being quite independently. The pole, too, had its origin in connection with ploughing. The ploughman used to carry a long stick by means of which he urged on the oxen, and, as all ploughmen used the same length of stick, it came to be a measure of length.

The different origins of the various measures account for the variety and the awkwardness of the numbers that make up the tables. Each new measure as it came into use had to be related to those already in existence, and thus the tables were built up in a haphazard manner. The remarkable thing is that they have been allowed to exist for so long.

The Metric System.

You have probably read in your history books about the French Revolution which began in the year 1789. That was a time of great cruelty and suffering in France, but out of it all, at least one good thing emerged. The revolutionaries were so anxious to effect a complete change in the country, that, as far as possible, they abolished everything that would remind them of what they considered to be the " bad old days." One of the things they decided to do away with was their system of weights and measures. In order to establish a new system, they called to their aid a number of scientific men whom they asked to advise them. This commission of scientists ultimately produced what we now call the Metric System. At the beginning

of their investigations, they decided that they would fix the standard length according to some natural measurement, so that, if the standard were lost or destroyed, it could easily be replaced by another exactly similar. It was for this reason that they fixed the length of the metre as the ten-millionth part of the distance from the North Pole to the Equator. You will probably ask how they could measure that distance seeing that the North Pole had not been reached, not to speak of the difficulties of measuring across seas and mountains. It would take too long to explain it here; suffice it to say that it was partly measured and partly calculated. From the metre all other measures were taken, as you will find out as you proceed in your course.

Not long after the new system was introduced, it was found that a mistake had been made in the original measurement of the distance from the North Pole to the Equator, but, as the new weights and measures were by this time in use, it was not thought advisable to make another change. Thus the metre, like the yard, is defined as the length between two lines on a metal bar, this bar being kept in Paris.

The great advantage of the Metric System over our British System is that the tables are so very simple. You may still remember the many hours you have spent in learning all the different tables—money, length, weight, etc. French boys and girls, on the other hand, learn practically only one table, and even that one is the simplest possible. Here it is:

10 millimetres	=	1 centimetre
10 centimetres	=	1 decimetre
10 decimetres	=	1 metre
10 metres	=	1 Decametre
10 Decametres	=	1 Hectometre
10 Hectometres	=	1 Kilometre

You will notice that all the numbers are the same, namely 10. Because of this fact, the Metric System is sometimes called the Decimal System. You will find in your work in physics how much more convenient it is to employ this system than our British System with its annoying variety of tables. Some bright boy might ask: "If it is so very convenient, why do we not adopt it in this country?" Well, many people are constantly asking the same question. There is in existence a Decimal Association, whose members have for years been advocating the abolition of our present standards and the adoption of the metric standards for all weights and measures; but the Government, in whose power it lies to make the change, have not yet seen their way to do so. No doubt it would cause a great deal of confusion and inconvenience at first, and people would take some time to become accustomed to the new system, but its ultimate advantages are so obvious that one wonders why there is any hesitation at all. It is used in most continental countries, and all scientific measurements in this country and throughout the world are made in metric units.

It is convenient for some purposes to know the relation between the metric units and the corresponding British units of length. The following are easily remembered but they are only approximate :—

1 metre = $1\frac{1}{11}$ yard
1 centimetre = $\frac{2}{5}$ inch
1 Kilometre = $\frac{5}{8}$ mile.

The other units will be spoken about in later chapters as they occur.

CHAPTER III

VOLUME

Meaning and Unit.

Everything, no matter how small it is, occupies a certain amount of space, or, to put it in popular language, it "takes up room." Well, the amount of space a body occupies is called its *volume*, and, just as we have certain units in which we measure lengths, so there are units for measuring volumes. If you take a cube, that is, a regular solid with six faces all squares, measuring 1 centimetre (or 1 inch) each way, then that cube is said to have a volume of 1 cubic centimetre (or 1 cubic inch). Then, just as we say that the length of a line is so many centimetres, so we say that the volume of a solid is so many cubic centimetres. Of course, a body may have a volume of 1 cubic centimetre without having the shape of a cube, so long as the amount of space it occupies is equal to that occupied by a cube whose edge is 1 centimetre: the shape does not matter in the slightest.

It will be obvious to you that, in the case of certain solids in the shape of rectangular blocks (such as a brick), the volume is easily found, for you can imagine it to be cut up into a number of cubes of 1 centimetre edge, and so, by measurement, you can find the number of cubic centimetres it contains, that is, its volume. The case of an irregularly-shaped body, however, is quite different. It too could be cut up into little cubes, but there would be a number of little bits left over whose volume could

not be found in this way. Before considering this any further, let us see how the volume of a liquid is measured.

Measurement of Volume of a Liquid.

Now a liquid has this property which a solid has not, namely, that it has no definite shape, but very conveniently takes the shape of any vessel into which it is poured. We might, therefore, have a vessel shaped in such a way that the volume could be obtained by simple measurement, as in the case of the rectangular block. Instrument makers, however, have saved us any trouble in this direction, for they provide us with several different kinds of instruments for measuring the volume of a liquid. The measuring jar (or graduated cylinder, as it is sometimes called), the burette, and the pipette are supplied for this purpose. It is useful to note the essential differences between these three instruments. The measuring jar measures directly the volume of liquid it contains; the burette gives, not the volume of liquid in it, but the volume of liquid run out of it; the pipette can be used to give only a certain definite volume of liquid, and is useful in transferring a certain amount of liquid from one vessel to another.

Two precautions are necessary in using all three instruments. (1) When water is contained in any vessel, the surface of the water is not absolutely flat; it seems to climb up the sides of the vessel. The narrower the vessel, the more easily this is seen. This curved surface is called the *meniscus*. In making an observation, it does not really matter whether the top or the bottom of the meniscus is taken, as long as the same side is always taken, but it is usual to take the bottom, and instruments are made on that understanding. (2) In making an observation the eye should always be on a level with the surface of the liquid, otherwise a slight error will be made, as is shown in the diagram on next page.

Volume of an Irregular Solid.

Let us now return to the problem of finding the volume of an irregular-shaped solid. These instruments that we have been discussing are, by themselves, of no use, for a solid does not accommodate itself to the shape of a vessel that contains it. If, however, some water is first poured into a measuring jar, and then the solid is lowered into the jar, the solid will displace, or push aside, a certain amount of water in order to make room for itself. How much water will it displace? Obviously an amount equal in volume to the volume of the solid. Thus the difference of the volumes read off before and after the solid is introduced gives the volume of the solid.

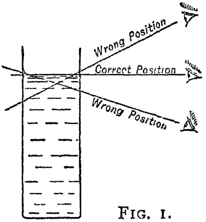


FIG. 1.

In the same way, the burette may be used to find the volume of a solid, provided, of course, the solid is small enough to get into it—for example, sand or pellets.

Archimedes and Hiero's Crown.

There is an interesting and oft-repeated story concerning the first occasion on which the volume of an irregular solid was found by displacement of water. In the year 287 B.C., there was born at Syracuse in the island of Sicily a man called Archimedes. He was a relation of the king, and was very rich, but he did not on that account live a life of luxury and ease as many men in such circumstances would have done. He had an inquiring mind, and proved to have a genius for invention, about forty different mechanical contrivances standing to his credit. He is sometimes called the "father of physics," because, so far as we know, he was the first to study physics as it ought to be studied, that is, experimentally.

On one occasion King Hiero was in a difficulty. He had given a certain weight of gold to a goldsmith to make a crown, but when the goldsmith delivered the finished article, the king, for some reason or other, suspected that, instead of using all the gold, he had kept some of it for himself, and mixed silver with the remainder in order to make up the necessary weight. He said nothing to the goldsmith, however, for he had no proof of his guilt, but sent for his friend Archimedes, who, he knew, was very clever, for by this time Archimedes had accomplished what in those days were considered marvellous things. The king told him of his suspicions, and asked him to find out whether the crown was made of pure gold or not. Here was a problem for the great man to solve, and it puzzled him greatly for a long time. The weight of the crown was exactly the same as the weight of the gold which the king had handed over to the goldsmith, and it looked like pure gold, but of course Archimedes knew that these facts were not sufficient to prove that it *was* pure gold.

One day he thought he had found the solution of the problem. He took some pure gold and some pure silver, and made two blocks of the same shape, one of gold and one of silver, each exactly the same weight as the crown; he found that the silver block was much larger than the gold block. But here another difficulty arose: the crown was not shaped like one of his blocks, so that he could not compare its size with the size of the blocks. He thought of melting down the crown, but it was beautifully made, and he did not want to destroy it. The problem now, however, was more definite: he must look for some method of finding the volume of the crown.

One day the solution came to him like a flash. In those days they had public baths—not swimming-baths, nor even the long narrow baths we use, but large cup-

shaped vessels. Well, this day Archimedes was having a bath, and, before he entered the bath, it was full to the brim with water. When he got in, of course, some water overflowed, and, on emerging, he saw that the water was no longer up to the brim. Suddenly it came to him: the amount of water that had overflowed was exactly equal to the volume of his own body. Why could he not find the volume of the crown in the same way? His excitement at the discovery was so great, that he forgot to dry and clothe himself, but rushed out of the building into the street shouting: "Eureka! Eureka!" (I have found it! I have found it!). No doubt people thought he had gone mad; but he disregarded every one and everything except the fact that he was now able to solve the problem that had baffled him up till then. On reaching his home, he at once got the crown, and lowered it into a vessel filled to the brim with water. Having done the same with the blocks of gold and silver, he compared the three volumes of water thus obtained, and found that the silver block displaced most water, and the gold block least; the crown displaced less than the silver block, but more than the gold block. Thus Archimedes proved that the crown was not made of pure gold.

The next question was: How much silver had been mixed with the gold? With this new method of finding volumes now available, he was not long in completing his investigation. He mixed gold and silver in different proportions, the whole always having the same weight as the crown, until he got a mixture that displaced the same volume of water as did the crown. He was then able to tell the king exactly how much gold the goldsmith had stolen. It is said that when the king accused the goldsmith of his fraud, the latter confessed, and he was made to restore the stolen gold, and was given a term of imprisonment.

Eureka Can.

This method, introduced by Archimedes, of finding the volume of an irregular solid is still used, a special instrument being made for the purpose. This instrument is called a Eureka or displacement can (see Fig. 2): the reason for the name will be obvious after reading the above story. It is a tin vessel provided with an overflow pipe. If it is filled with water, and a solid lowered into it, an amount of water will overflow equal in volume to the volume of the solid. The volume of the water can be measured with a measuring jar, and that gives the volume of the solid.

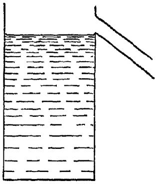


FIG. 2.—The Eureka Can.

CHAPTER IV

WEIGHT

Newton and the Falling Apple.

You have no doubt seen certain shopkeepers use a spring balance, that is, a balance which has only one pan, and which indicates weights by the stretching of a spring. Did you ever ask yourself what it is that pulls the spring down when any article is placed on the pan? "Oh," you say, "that is simple: the weight of the article stretches the spring." But what do you mean by the "weight" of it? Probably you think that is too trivial to worry about: weight is just weight, and that is the end of it. So people thought until a certain famous mathematician and philosopher showed them their mistake. This was Sir Isaac Newton. Newton's boyhood was remarkable for the decided taste he showed for mechanical and scientific pursuits. Instead of employing his play-hours in sports and games, he was making models of machinery, water-clocks, and sundials. One day in the autumn of 1665 (so the story goes), he was sitting in his garden when an apple, blown from the tree above him, fell to the ground at his feet. Newton's ever-active brain got to work on this apparently insignificant incident, and he asked himself: "Why did that apple fall to the ground? A lifeless object cannot move of itself; if it does move, some force must either be pulling it or pushing it." Ultimately, after many experiments and observations, he was led to the conclusion that it was the earth that pulled the apple towards it, and that the earth pulls everything

towards it. Incidentally it might be mentioned that this same force by which the earth pulls objects to it also keeps the moon from flying off into space, and similarly, the attractive force exerted by the sun keeps the earth and the other planets revolving round it.

So you see that to ask what was meant by "weight" is not such a trivial question after all. The weight of a body is the force by which it is attracted (or drawn) to the earth. This force is called the force of gravity. Now this force is not the same at all points on the surface of the earth. It has been found that the amount of the force depends on the distance of a body from the centre of the earth. Hence, since the earth is not a perfect sphere, but is flattened at the poles, the distance from the surface to the centre of the earth is different at different places, and thus the weight of a body will be different in different latitudes. Even in the same latitude, the weight will be different at different elevations. If a body is weighed at sea-level, and is then taken up a hill and weighed there, its weight will be found to have altered.

Now, you may ask, and quite properly too: "If the weight of a body changes as it is moved about from place to place, does not that confusion arise which was spoken about in the introductory chapter? If it would be confusing to have different standards of length, surely it would be as confusing to have different standards of weight." Before this question is answered, you must have a little more information.

Mass and Weight.

When you go to a grocer's shop and ask for a pound of sugar, the grocer puts a pound weight in one scale-pan, and the sugar on the other, adding or taking away sugar until the two just balance. Now, if he took the balance to the Equator, would you get the same amount of sugar

or a different amount? Think twice before you answer that question. When the sugar and the pound weight exactly balance here in the shop, the earth is pulling down both with the same force. At the Equator this force would be different, but it would act equally on the sugar and the pound weight, so that exactly the same amount of sugar would balance the pound weight at the Equator as balanced it here. If, however, a spring balance is used, the case is entirely different, as you can easily see

In taking a body from one place to another, there is one thing that does *not* change, and that is the amount of matter in it. This is called its *mass*. When a body is "weighed," what is really done is that its mass is compared with a standard mass, such as a pound. What you get from the grocer is a mass of sugar equal to the mass of a pound. It is very unfortunate that the word "weight" is commonly used to denote both the quantity of matter in a body and the force exerted by the earth on it, when it ought to be reserved solely for the latter. Now that the distinction has been made, the word "weight" will be used in future in its ordinary sense. When you come to study another department of physics, namely, mechanics, you will have to be more careful in its use.

The Balance.

The rifle has been described as "the soldier's friend." Great pains are taken to let the soldier understand its construction, the use of each of its different parts, and how to keep it in good condition. He is also given a great deal of practice in its use. Now, in some respects, the balance might be described as "the scientist's friend," for no one can go very far in the study of science without calling it to his aid, and little progress was made in scientific discovery until the value of weighing was realised. And as with the rifle, so with the balance, it has to be looked after, and

the best way of looking after it is to treat it with respect, and to handle it with care. The knife-edges, though made of agate, a very hard substance, are liable to get broken if the balance is roughly handled, or if it receives a sudden jar; if that happens, its accuracy is greatly impaired. You must realise that a very little will put it out of order. The weights too must be looked after; they must not be touched with the hands, but with the forceps provided, for contact with many hands would soon alter their weight.

When you have had a little practice in using the balance, you will be able to weigh quickly and accurately; but accuracy is more essential than speed. In all scientific work, accuracy is the first essential. Mistakes are easily made, and you must take all possible precautions to guard against them.

Unit of Weight.

One of your earliest experiments with the balance will be to find the weight of 1 cubic centimetre of water, which you will find to be 1 gram. Now this is not a coincidence—it does not just happen that there is such a simple relation between the volume and the weight of water. When the system of weights and measures in France was changed at the time of the Revolution, and the Metric System was introduced, it was then decided that the standard of weight should be the weight of 1 cubic centimetre of water under certain conditions which will be mentioned later (see p. 104). This standard was called the gram, the subdivisions and multiples of which were fixed in the same way as those of the metre, as shown in the following table, which you should compare with the table of length given on p. 7:

10 milligrams	= 1 centigram	10 grams	= 1 Decagram
10 centigrams	= 1 decigram	10 Decagrams	= 1 Hectogram
10 decigrams	= 1 gram	10 Hectograms	= 1 Kilogram

A Kilogram is approximately equal to $2\frac{1}{5}$ lb. The fact that 1 cubic centimetre of water weighs 1 gram is a very simple and convenient relation between the volume and the weight of water; for, if you know the weight of a certain quantity of water, you can immediately tell its volume, both being represented by the same number. You may have noticed that the instruments you have used for measuring the volumes of liquids are not very accurate. With the measuring jar, you can measure only to the nearest cubic centimetre, and with the burette to the nearest tenth of a cubic centimetre. On the other hand, you can weigh correctly to the hundredth or even thousandth of a gram, and hence, by using the balance, you can find the volume of a certain quantity of water correctly to the hundredth or thousandth of a cubic centimetre.

Eureka Can.

In the previous chapter, reference was made to the Eureka or displacement can. It was stated there that, by measuring the volume of water that overflows when a solid is lowered into the vessel, the volume of the solid is obtained. There are, however, two objections to this: (1) The volume found thus is correct only to the nearest cubic centimetre, and often greater accuracy is required. (2) As a rule, the water would be allowed to overflow into a beaker and then transferred from the beaker to a measuring jar. But there is some water left in the beaker, for, as can be seen, the inside of the beaker is wet. It is better if the water is allowed to overflow into a weighed beaker, and then weighed.

Having learned to find the weight and the volume of solids and liquids, you are now ready to go on to make other measurements, and to find out certain properties of matter. Keep in mind that 1 cubic centimetre of water weighs 1 gram.

CHAPTER V

DENSITY

Meaning and Unit.

If you were to pick up a small piece of lead pipe, you might exclaim: "How heavy it is!" If you were to lift a bag of feathers, you would probably say: "Isn't it very light?" Yet if you were actually to weigh the two, you might find that the bag of feathers was heavier than the piece of lead pipe. How then would you explain your remarks? Obviously you mean that *for its size* the piece of lead pipe is very heavy, and *for its size* the bag of feathers is very light.

Every substance is composed of very small particles of matter. In what we usually refer to as a heavy substance, such as lead, those particles are packed very closely together, whereas in what we call a light substance, such as wood, the particles are not so closely packed together. But to speak of heavy and light substances in this loose manner will not do for scientific work, where accuracy in speech as well as in work is essential, For the purpose of comparing two substances, the term *density* is used. The density of a substance is the weight of unit volume of it: in the Metric System it is the weight of 1 cubic centimetre; in the British System it is the weight of 1 cubic foot. The point to note particularly is that, in order to compare two substances, equal volumes must be taken. It is really immaterial whether you take 1 or 50 cubic centimetres of the two as long as you take the same

volume of each, but it is generally most convenient to take 1 cubic centimetre. So density is always expressed as so many grams per cubic centimetre (or pounds per cubic foot).

Its Measurement.

The next question that arises is : How is the density of a substance found ? What measurements must be made in order to find the density, say, of a stone ? Before you can find the weight of 1 cubic centimetre of the stone, you must obviously know the weight of the stone, and the number of cubic centimetres in it ; in other words, you must find its weight and its volume. Knowing these, the density can easily be calculated. Its weight, of course, is found simply by weighing it on a balance, and its volume may be ascertained by any of the methods previously mentioned.

If, in this way, the densities of various substances, solid and liquid, are found, then a glance suffices to tell which is the most dense and which is the least dense ; any two may be compared simply by comparing the numbers representing their densities. Without those numbers it would be impossible to compare two substances whose densities are nearly equal, for example iron and tin, whose densities are 7·8 and 7·3 grams per cubic centimetre respectively.

Archimedes' discovery explained.

It is worth while noting here that Archimedes, when he solved the problem of the crown, really compared its density with the density of pure gold and that of pure silver. Although he did not use the term "density," the idea which the word represents must have been at the back of his mind. Let us suppose that the weight of the crown was 1000 grams. The density of pure gold is 19·3

grams per cubic centimetre, and that of pure silver is 10·5 grams per cubic centimetre. For the sake of simplicity, call these densities 20 and 10 grams per cubic centimetre respectively. Now what Archimedes did first of all was to make blocks of gold and silver, each weighing 1000 grams, and he found that the silver block was about twice the size of the gold block. Taking the round numbers for the two densities, the volume of the silver block would be 100 cubic centimetres, and that of the gold block 50 cubic centimetres. Then these blocks would displace 100 and 50 cubic centimetres of water respectively. The crown, however, he found to displace a volume of water somewhere between 50 and 100 cubic centimetres, showing that the volume of the crown was greater than that of the gold block, but less than that of the silver block. Hence, since the weight of each was 1000 grams, the density of the crown was intermediate in value between that of gold and that of silver.

Purity of a Substance.

Now a process similar to Archimedes' experiment (but carried out very differently) is used to-day for testing the purity of substances. It rests on this fact, which Archimedes assumed, namely, that as long as a substance is pure its density never varies, but the addition of other substances to it will as a rule alter its density. Thus impurities may often be detected by the simple process of finding the density; but, as will be explained in the next chapter, this test is sometimes not effective by itself. King Hiero's crown was the correct weight, and it looked like gold, but appearances are proverbially deceptive, and the density test in this case detected the fraud.

CHAPTER VI

FLOATING BODIES

Measurement of their Density.

So far, no mention has been made of solids that float when placed in water. Obviously the various methods that have been mentioned for finding the volume of a solid cannot, without some modification, be employed in finding the volume of a floating solid. A solid that sinks in water displaces its own volume of water, but a solid that floats in water does not do so. In the latter case, the volume of water displaced will be equal only to the volume of that part of the solid under the surface of the water. Thus the volume of, say, a cork cannot be found simply by placing it in a measuring jar and noting the rise of the water, or by placing it in a Eureka can and weighing the water displaced. In both cases, the volume of only a part of the cork would be found.

In order to determine the volume of the cork, some means must be found to get it completely immersed in water, so that it will displace its own volume of water. The most convenient method of doing this is to attach to the cork some solid heavy enough to sink it ; then the combined volume of the cork and sinker can be found just as if they were one heavy solid. If then the volume of the sinker is found separately, subtraction will give the volume of the cork. Having found its volume, it is an easy matter to find its density.

Comparison with other Substances.

If you find the densities of a large number of floating bodies, and compare them, you will discover that they are all less than 1 gram per cubic centimetre, that is, less than the density of water. On the other hand, the densities of solids that sink in water are all greater than 1 gram per cubic centimetre, that is, greater than the density of water. If you take a liquid other than water, and try putting into it different solids whose densities you know, you will find that those solids whose densities are greater than the density of the liquid will sink, while those whose densities are less than the density of the liquid will float. If a certain solid happens to have the same density as the liquid, it will remain suspended in the liquid, neither sinking nor floating. Probably the greatest density you have come across yet is that of lead, which is about 11·4 grams per cubic centimetre; and, of course, lead sinks in water. If, however, you put a piece of lead into mercury, whose density is 13·6 grams per cubic centimetre, you will find that the lead will float.

Weight of a Liquid displaced.

It was said above that the volume of a floating body could not be found simply by placing it in a Eureka can, because it does not displace its own volume of water. If, however, the water displaced when a cork alone is placed in a Eureka can is weighed, and the cork itself is weighed, a rather remarkable result will be obtained. It will be found that the *weight* of water displaced is equal to the *weight* of the cork. To put it in a slightly different way, a floating body displaces its own *weight* of water. Do not confuse this with the fact that a solid that sinks in water displaces its own *volume* of water: the two facts are entirely different, and have no connection with each other. If any other liquid is substituted for water, the

result is found to be the same, so we can make a more general statement, and say that a floating body displaces its own weight of any liquid.

The Common Hydrometer.

Suppose now that you have two vessels, one containing a liquid whose density is 1·2 gram per cubic centimetre, the other a liquid whose density is 0·8 gram per cubic centimetre, and a solid that will float in both liquids. A convenient solid would be a wooden rod weighted at one end to make it float upright. Suppose that the weight of the rod is 24 grams. Then the rod will displace 24 grams of each liquid when floating in it. In the case of the first liquid, since 1 cubic centimetre of it weighs 1·2 grams, the rod will displace 20 cubic centimetres of the liquid, since 20 cubic centimetres weigh 24 grams. In the case of the second liquid, 1 cubic centimetre weighs only 0·8 gram, and the rod will therefore displace 30 cubic centimetres of it, since 30 cubic centimetres of this liquid weigh 24 grams. The rod displaces 24 grams of each, but 20 cubic centimetres of the first, and 30 cubic centimetres of the second—a difference in volume of 10 cubic centimetres. Now what exactly does this mean? In the case of the second liquid, although the *same weight* is displaced as in the case of the first, a *greater volume* is displaced. How is the greater volume displaced? There can be only one answer to that, namely, that the rod must have sunk farther into the liquid. Thus a floating body will sink farther in a liquid with a low density than it will in a liquid with a high density.

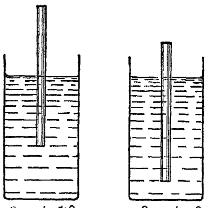


FIG. 3.

This fact is the principle on which a very useful instrument called a hydrometer is constructed. It is generally made of glass. A bulb at the bottom contains mercury, or some other heavy substance, and immediately above this bulb is another containing only air. This arrangement ensures that the instrument will float upright. Then there is a long narrow graduated stem, marked off and numbered, each of the numbers corresponding to a certain density. With the help of this instrument, the density of a liquid may be found very quickly and very accurately. Hydrometers are generally made in sets, each one having a different range of densities, because, if only one were used, the stem would have to be inconveniently long. A table is supplied giving the densities corresponding to the numbers on the stem. The hydrometer is one of the oldest of scientific instruments; it was invented by the Greeks probably in the fourth century A.D. It was first used in the testing of drinking-water. In those days, it was thought that "hard" water was not wholesome, and the hydrometer indicated the quality of the water.

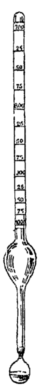


FIG. 4 —The Common Hydrometer.

Uses of the Hydrometer.

The hydrometer is not confined to scientific laboratories, in fact, it is seldom used there; it is used in different industries for finding the densities of liquids, and it is generally named according to the use to which it is put. For example, if it is used to find the density of salt water, it is called a salinometer; if to find the density of alcoholic

liquors, an alcoholimeter ; if to find the density of milk, a lactometer. The reason for these names will be obvious from their derivations. In the last chapter it was stated that the density of a substance is an indication of its purity, and here we have a practical application of that fact. Take, for instance, the case of milk. Were it not for the law, we should be at the mercy of dishonest dairymen who would not scruple to add water to their milk in order to make a bigger profit. The law, however, protects us from such mean tricks, and Government inspectors have the right to go to any dairyman at any time and demand a sample of the milk he is selling in order to see if it is up to the required standard. Now one of the tests the inspector applies to the milk is to find its density, using a lactometer. This test by itself, however, may not reveal the fact that the milk has been tampered with, for this reason : the cream is less dense than the rest of the milk ; water also is less dense than the rest of the milk ; hence the cream might be skimmed off, and water added, without altering the density of the milk, if care were taken to add just the necessary amount. Thus, if the density of the milk is correct, the inspector has to apply a further test, namely, to find out the amount of fat it contains, because all the fat is found in the cream. If there is a marked deficiency of fat, then the milk is condemned, and the dairyman prosecuted. If, on the other hand, water has been added to the milk without taking off the cream, then the lactometer detects the fraud at once, with disastrous consequences to the would-be profiteer.

Nicholson's Hydrometer.

A hydrometer by which the density of a solid may be found was invented by William Nicholson in 1784. He was a teacher of mathematics and physics in London, and published a large number of papers on scientific

instruments. In a description of his invention, he speaks of the common hydrometer and ascribes its invention to a certain Mr. Quin; but he is in error there, for, as already stated, the Greeks used it in the fourth century. Nicholson's hydrometer is seldom used, but it is an interesting instrument in itself.

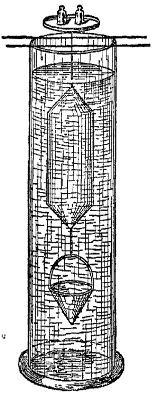


FIG. 5.—Nicholson's Hydrometer.

We have seen that the depth to which a floating body sinks in a liquid enables us to find the density of the liquid; but if the density of the liquid is known, the density of the solid can be found. This determination, however, is not very important, so, having mentioned it, we shall pass on.

Icebergs.

It is a matter of common knowledge that ice floats in water. Does not that strike you as curious? Probably you have become so accustomed to the fact, that you have not thought about it. Ice is merely solid water, and one would think that when water solidifies the particles of water would come closer together, and that therefore ice would be denser than water. But that cannot be the case, for, seeing that ice floats on water, its density must be less than the density of water: there is not so much matter in 1 cubic centimetre of ice as there is in 1 cubic centimetre of water. As a matter of fact, the density of ice is about 0·9 gram per cubic centimetre, while, of course, that of water is 1 gram per cubic centimetre. We cannot investigate the matter further at this stage (see Chap. XIX.); all we are concerned with at present is the fact that ice floats on water.

Icebergs are a constant source of danger to mariners

in certain parts of the sea. At night or in foggy weather, a ship may easily be wrecked by the mere impact with one of these enormous mountains of ice. It was from this cause that the huge liner, the *Titanic*, was wrecked in the North Atlantic while on her maiden voyage in 1912. It is believed that a large hole was torn in the bottom of the vessel by that part of the iceberg below the surface of the water. It was confidently asserted that this ship was unsinkable, but the terrible disaster, involving the loss of hundreds of lives, illustrated how puny is the product of man's work when it is pitted against the forces of nature.

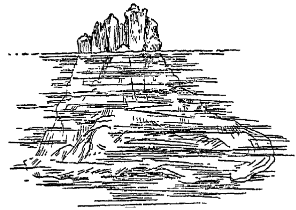


FIG. 6.—An Iceberg.

When dealing with icebergs, the point to be remembered is that by far the greater part of any iceberg is below the surface of the sea. The density of ice is about 0·9 gram per cubic centimetre, and the density of sea-water is about 1·025 gram per cubic centimetre. Hence an iceberg will float with about $\frac{9}{10}$ of its volume submerged, and only $\frac{1}{10}$ above the surface. Herein lies its danger. An iceberg that appears comparatively small may extend a great distance, not only downwards, but outwards as well, constituting a danger that is all the greater because it is invisible.

Floating of a Ship.

As illustrating how the primitive scientists fell into error, it might be mentioned that a certain Greek, Aristotle by name, *thought* that the sinking or floating of bodies depended on their shape. One would think that it would have been a very easy matter to refute this theory by the

simple expedient of putting a great number of solids of different shapes into water, and observing the result. But no; from one, or possibly a few, particular cases, Aristotle put forward the general statement, and the curious thing is that men took his word for it: they never for a moment dreamt of doubting his word, and trying to find out for themselves if he were right or not. "Woe unto him who dared to contradict a statement made by Aristotle!" It was left for Galileo, an Italian scientist of the seventeenth century (born in the same year as Shakespeare) to show that it is the density and not the shape of a body that determines whether it will float or sink. The plate which faces page 80 of this book serves to remind us that Galileo was also the first to use a pendulum to measure time.

Yet, as is often the case with incorrect theories, there was an element of truth in Aristotle's statement. From your experiments you know that the density of steel is about 7·8 grams per cubic centimetre, and even from ordinary everyday experience you know that steel sinks in water. How is it then that a ship which is almost entirely made of steel will float? The reason is that the ship is so constructed that, when it enters the water, the volume of water displaced is much greater than the volume of steel immersed, and, as no solid displaces more than its own weight of a liquid, the ship goes down as far as possible, and displaces its own weight of water. A ship must be regarded as consisting of not merely the material of which it is built, but as the material plus the contents of the ship, this latter factor including air. Thus its *average* density, taking everything into consideration, is less than 1 gram per cubic centimetre. If a hole is made in the bottom of the ship, water enters and adds to the weight of it, and it therefore sinks farther in order to displace its own weight of water. If water continues to enter.

a point will be reached when the ship cannot displace its increased weight, and it will then sink to the bottom.

Plimsoll Line.

If a ship is loaded with a cargo at Glasgow, it has been observed that, as it sails out of the river, and down the Firth of Clyde, it rises slightly out of the water. How can this be explained ? The explanation depends on the fact that at Glasgow the water is fresh while in the Firth it is salt, and that salt water has a slightly greater density than fresh water. We are really back to the principle of the hydrometer again. The ship, passing from a liquid with a small density (fresh water) to a liquid with a greater density (salt water) does not require to displace so great a volume of the latter in order to displace its own weight, hence it does not sink so far in the salt water. On the side of every ship there is a circle with a horizontal line passing through the centre, which is put there by the Board of Trade to indicate the depth to which it may be safely loaded in sea-water. This is called the Plimsoll line, Plimsoll being the man who suggested this safeguard.

CHAPTER VII

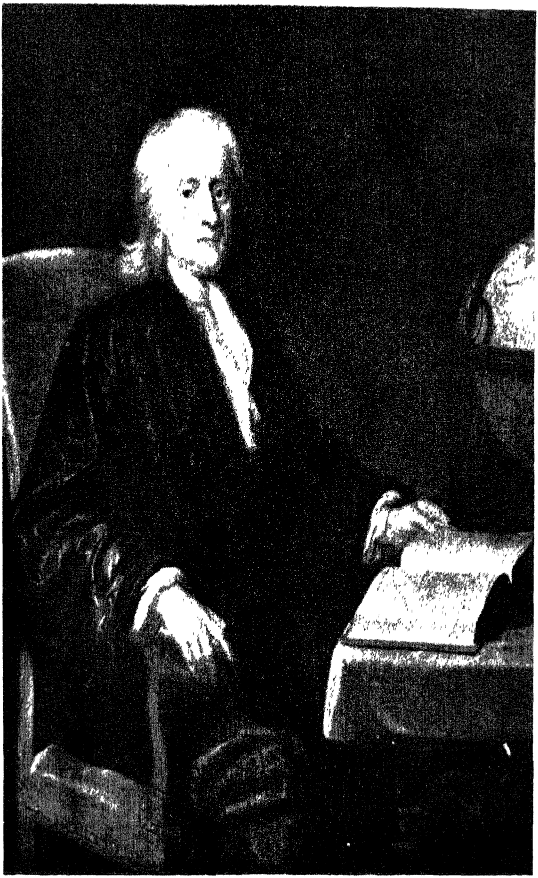
SPECIFIC GRAVITY

Meaning and Definition.

Since density is the weight of unit volume, it follows that the density of a substance will be represented by different numbers in two countries where the weights and measures are different. To take the example of the common substance water, its density in the Metric System is 1 gram per cubic centimetre, whereas in the British System it is about 62½ lb. per cubic foot. In order to overcome this difficulty, it has been agreed to compare the densities of all substances with the density of water. If the density of lead is 11·4 times greater than the density of water in Britain, it will be 11·4 times greater than the density of water in any other country, no matter what system of weights and measures that country has. The numbers obtained by thus referring all densities to that of water are quite independent of the units employed, and are therefore the same in all countries. This number for each substance is called its specific gravity (sometimes relative density). It may be defined as the number of times the density of the substance is greater than the density of water. Not that specific gravity has no name: it is simply a number.

Measurement.

In practice, it is not necessary to know the density of a substance in order to find its specific gravity. Instead of dividing the weight of 1 cubic centimetre (that is, the



SIR ISAAC NEWTON.

From the portrait by John Vanderbank in the National Portrait Gallery.

ARCHIMEDES

From an old woodcut in the British Museum.

density) of the substance by the weight of 1 cubic centimetre of water, we might divide the weight of 10 cubic centimetres by the weight of 10 cubic centimetres of water, and obtain the same result. In fact, any volume may be taken *so long as equal volumes are compared.* For practical purposes, specific gravity may be considered as the number of times the weight of any volume of a substance is greater than the weight of an *equal* volume of water. Note that it is not necessary to know what the volume is, if it is known that it is the same volume in each case.

To illustrate the method of finding specific gravity, consider the use of the specific gravity bottle, which, as its name indicates, is made and used for this special purpose. This bottle, having a hole through the stopper, can be completely filled with any liquid. If it is weighed empty, then full of a liquid, and then full of water, the weights of liquid and of water filling the bottle can be obtained by subtraction. You do not know what the volume of the liquid or of the water is, but you do know that they are the same, for the same bottle was completely filled in both cases. Hence, if you divide the weight of the liquid by the weight of the water, you will obtain the specific gravity of the liquid.

On the same principle, the specific gravity of a solid can be found by the Eureka can without actually finding the density, or even the volume of the solid. The solid is weighed, and the water it displaces is weighed. The water having the same volume as the solid, the specific gravity is found in the usual way.

In comparing different substances it is more usual to take their specific gravities than their densities, because of the fact that the specific gravity of a substance is always the same no matter what units are employed. Nearly all that has been said in regard to density in the preceding chapters applies to specific gravity. In the Metric System,

because 1 cubic centimetre of water weighs 1 gram, the numbers that represent densities also represent specific gravities—another instance of the simplicity of the system.

The term "specific gravity" is one of the few scientific terms that have come down unchanged from antiquity. We are told that it was used nearly a thousand years ago by the Arabs, who at that time were the pioneers of progress in science.

CHAPTER VIII

ARCHIMEDES' PRINCIPLE

Archimedes.

Sometimes, in the light of our superior knowledge, we are inclined to laugh at the old scientists for their curious ideas, their silly notions, and their fantastic theories, but there are some for whom we must always have a profound respect. Euclid, for example, who lived at Alexandria in Egypt about the year 300 B.C., and whose book is thus much older than the New Testament, collected all that was then known about geometry, added numerous discoveries of his own, and issued them in his famous book, *The Elements.* The remarkable fact is that this is still the standard work on the subject; with only slight modifications, it is used to this day by those learning geometry.

Another man whose name is still held in respect is Archimedes, to whom we have already referred in connection with his solution of the problem of King Hiero's crown. He was a most remarkable man. As a youth he went to Alexandria to learn mathematics, and he just missed being a pupil of the great Euclid. Returning to Syracuse in Sicily, his birthplace, he continued to study mathematics, and he also turned his mind to physics. Now Archimedes differed from those who had preceded him in that he *applied* his knowledge of science to everyday life. We are accustomed nowadays to look for applications of every scientific discovery; a great phil-

osopher, Francis Bacon, said: "Science ought to bear fruit by the improvement of the arts," and almost every moment of our lives we are indebted to science for some necessity or comfort or luxury of life. Before the time of Archimedes, men studied science for its own sake, not for what it would bring them either in money or in comfort. They would have considered it beneath their dignity to use their knowledge for any useful purpose. Archimedes, however, had no such scruples. He invented a screw for raising water which is still called by his name; he launched ships by means of levers; he designed large catapults and other apparatus for use in war; and the story is told how he used his knowledge of the laws of light and heat to set fire to an enemy's ships by means of a number of mirrors which concentrated the rays of the sun on them. His discoveries in mathematics were no less striking than his achievements in physics, and altogether they stamp him as one of the greatest of the ancient scientists.

Archimedes met his death at the hands of a Roman soldier in 212 B.C. The Romans were waging war on the Syracusans, and, when the city fell, a Roman soldier found Archimedes working out some problem with a stick for a pencil and sand for paper. When the soldier asked him his name, the great man told him to wait till he had solved his problem, and not to tread on his circles. The soldier, enraged at what he considered his insolence, killed him.

Archimedes' Principle explained.

The particular discovery of Archimedes with which we are concerned in this chapter was really a minor one, but, probably because it still bears his name, it is the one we immediately think of when his name is mentioned.

If you tie a piece of thread to an ordinary brick, and try to lift it by means of the thread, you will probably find that the thread will break. If, however, before lifting it by the

thread, you place it in a bucket of water, you will be able to lift it in the water without breaking the thread. Again, those of you who go bathing at the seaside know that, while in the water, you can walk on your toes without feeling the discomfort you would feel if you tried to perform the same feat out of the water.

The explanation of facts such as these is that the water buoys up the brick and the body: in each case part of the weight is taken by the water. When the brick is placed in the water, the latter seems to try to push the brick out again, and though the brick wins in this trial of strength, the water still continues to push it, and so the brick appears to be lighter in weight. In the case of floating bodies, it is the water that wins, since it succeeds in keeping the solid on the surface.

Now Archimedes must have noticed that solids appear to lose part of their weight when placed in a liquid, but instead of merely sitting down and thinking about it, as some of those early scientists would have done, he set to work with his balance to see what he could find out. He took a number of solids differing in substance, in shape, and in size; he weighed them in the ordinary way, and then he weighed them while they were completely immersed in water. He found that the second weight was less than the first, and he also found that the difference in weight was exactly equal to the weight of water which the solid displaced. As a matter of fact, any other liquid may be substituted for water with the same result. This is known as Archimedes' Principle, which may be stated thus: When a body is weighed in air and then in a liquid, it appears to lose weight, and the apparent loss in weight is equal to the weight of liquid displaced by the body. Notice that the body only *appears* to lose weight, for, of course, no part of the weight is actually lost: it is the water pushing against it that causes the difference.

Applications of Archimedes' Principle.

This fact discovered by Archimedes can be employed in finding (1) the volume of a solid, (2) the density of a solid, (3) the specific gravity of a solid, (4) the density of a liquid, (5) the specific gravity of a liquid, and, given a good balance and careful weighing, the results obtained by this method are very accurate. Not only is it an accurate method, but it can be done in a very short time. For these reasons, it is frequently employed in the laboratory.

CHAPTER IX

DENSITY OF GASES

So far, we have considered the volume, density, and specific gravity of solids and liquids, but you do not require to be told that matter exists in a third state, namely, that of a gas. You are familiar with coal-gas, by which your homes are probably illuminated; those of you who possess bicycles know about acetylene gas, which has a peculiar smell, and which is used in bicycle lamps; but the commonest gas, and one without which we could not live, is air.

Has Air Weight?

The first question that arises when dealing with air is: Has it any weight? If that question were put to you, and an immediate answer demanded, you would probably say that air has no weight. On being asked your reason for saying so, you would no doubt answer that, if it had weight, you would feel it. Our senses, however, are not nearly reliable enough for scientific purposes. For example, if you depended entirely on your sense of sight when a conjurer pretends to produce rabbits out of an empty hat, you would believe that he actually did what he pretended to do, whereas your reason tells you that it is only a trick—a very clever trick certainly, but still only a trick. So we must investigate this question as to whether air has weight.

But how can we weigh air? How can we obtain a completely empty vessel? When we speak of an empty vessel in everyday language, it is always understood that it is full of air, but, for our present purpose, we must get rid of all the air, for, if we can weigh a vessel without

air, and then the same vessel full of air, we shall be able to tell whether air has weight.

One Method of obtaining a Vacuum.

Consider for a moment what happens when water is boiled in a kettle. Steam is produced, and it comes out of the spout with considerable force. Is it not possible that when the steam is driven out, any air that was in the kettle is driven out as well? It is not only possible but probable. A very simple experiment will test this. If a flask (Fig. 7) containing some water is fitted with a stopper through which passes a tube leading under water, and the flask is heated till the water boils, it is seen at once that,

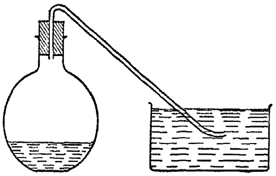


FIG. 7.

FIG. 8.

at least *some* of the air is driven out, for it can be seen bubbling through the water. After a time no more air-bubbles appear, but we cannot assume from that fact that there is no air left in the flask. If, however, the heating is stopped, the steam in the flask condenses, and water comes into the flask through the tube, filling the flask completely. This shows that *all* the air has been expelled, for if any air had been left, the water would not have filled the flask. Here then is a means of obtaining a vessel free of air.

Density of Air.

A flask (Fig. 8) is fitted with a stopper through which passes a short glass tube with a piece of rubber tubing attached, and a clip is held in readiness. Some water is

boiled in the flask for a few minutes, thus driving out the air, and the clip is put on and the heating stopped simultaneously. When the flask has cooled, it is weighed. On opening the clip, air rushes in with a hissing noise, and when it is weighed again, it is found that there is a slight increase in weight which must be due to the air. Hence air *has* weight—very small certainly, but quite weighable. The volume of the air which has just been weighed can be found by subtracting the volume of water in the flask from the capacity of the flask, and since the weight and the volume of the air are known, the density can be calculated.

In this experiment you may not obtain a very good result for the density of air; it depends on circumstances which you will learn about later in your course. For finding the density of gases accurately, greater skill and knowledge are required than you possess at this stage. The important point to note is that air has weight.

Archimedes' Principle applied to Gases.

When a solid is weighed in air, the air affects its weight in the same way as water affects the weight of an immersed solid, and Archimedes' Principle can be applied to gases as well as to liquids. In the case of air, however, the buoying-up effect is not nearly so pronounced, because of the smaller density of air. The weight of air displaced by a solid is very small, and that is the difference between the weight of the solid in air and the weight in a vacuum—that is, a space without air. When the solid is very large, the effect is quite appreciable. For example a balloon displaces a very large quantity of air, and is therefore buoyed up to a considerable extent. Of course, this does not account for the rising of the balloon into the air; it must be filled with a gas whose density is less than the density of air. Hydrogen is the gas often employed, but another gas called helium has recently come into use which is preferable to hydrogen because it is not inflammable.

CHAPTER X

PRESSURE

U-tube with Equal Limbs.

If water (or any other liquid) is poured into one of the limbs of a U-tube, it rises in the other limb until it stands at the same level in both. You might have guessed that it would do so before you tried the experiment. The obvious explanation is that the water in each limb balances that in the other limb, or, to express it more exactly, the weights of the two columns of water are equal. If more water is poured into one limb so as to make the water in that limb heavier than that in the other, then some water will flow from that limb to the other, and the levels will be the same again.

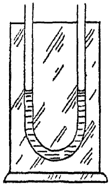


FIG. 9.

U-tube with Unequal Limbs.

If now you take a U-tube with limbs of unequal diameter, you will probably be surprised to find, on pouring water into it, that the water stands at the same level in each, as in the previous experiment. Now this time it cannot be said that the weights of the two columns of water are equal, for obviously the weight of water in the wider limb is greater than the weight of water in the narrower limb, and yet the water stands at the same level in both limbs. Apparently we shall have to find some other explanation.

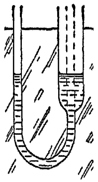


FIG. 10*a*.

Imagine in the wider limb a column of water exactly

equal in every respect to the column in the narrow limb (as indicated by the dotted line in Figs. 10*a* and *b*); then it is clear that these two columns will balance. But what about the weight of the water round about this imaginary column? What is supporting it? Well, if it is not being supported by the water, there is only one other thing that can possibly support it, and that is the glass tube at that part where it tapers down to the diameter of the narrow limb. This will be more obvious if you take the case where the wide limb, instead of tapering off gradually, ends abruptly, leaving a ledge on which the water rests.

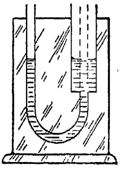


FIG. 10*b*.

Pascal's Vases.

Pascal's Vases, so called after the French scientist Pascal who devised them, may be considered as several U-tubes combined, the shapes as well as the sizes of the different limbs being quite different. No matter what the shape or the size of the vessels may be, so long as there is connection between them, water stands at the same level in each.

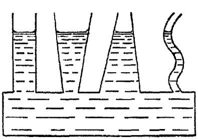


FIG. 11.

A Liquid tends to find its own Level.

These last three experiments illustrate a general principle which may be stated thus: A liquid always tends to find its own level. Note that the statement is "*tends* to find its own level," for it may be prevented from doing so in some way. For example, if you close one limb of a U-tube with your finger, and pour water into the other limb, the levels will not be the same, because you are preventing the air that is in the tube from escaping, as it

would do were your finger not there. You will come across some examples of this later.

Illustrations of this Principle.

There are many more ordinary illustrations of this principle, some of which will readily occur to you. (1) To begin with a very simple one, when you pour water into a teapot or kettle, the level of the water in the pot or kettle and the spout is the same. You can easily verify this for yourselves. (2) On motor cycles and motor cars there is generally a small glass tube connected with the petrol tank to indicate the amount of petrol in the tank. Since there is free connection between the tube and the tank, the petrol stands at the same level in both, and the cyclist knows that when the petrol in the tube is low, the tank must be replenished. The tube is called a gauge. (3) Artesian wells, too, illustrate this same principle. Water (rain) enters the ground at A (Fig. 13) between two layers of soil, B and C, which it cannot pass through, both layers being saucer-shaped with a permeable layer between them. Gradually the water collects in this space between the

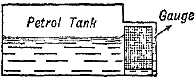


FIG. 12.

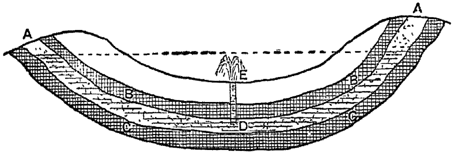


FIG. 13.

two impermeable layers, first at the lowest point D and later rising on both sides. If, after this has gone on for many years, a boring is made at the lowest point of the

"saucer," that is, at E, a spring will be formed, for this boring is a means whereby at this point the water can find its own level. If the difference in level between the top of the boring and the surface of the water in the ground is great enough, the water will gush high into the air. (4) To supply water to a town or village, a reservoir is constructed on a hill. Water will then of its own accord flow down to the town, and be available when led into the houses. It cannot simply flow down to the lowest point and stay there; it attempts to rise again to the level from which it started. Hence any house below the level of the reservoir can be supplied with water, but a house higher than the reservoir will not receive a supply of water unless it is forced to that height by means of a pump. (5) Somewhere about the time when Archimedes was alive, there lived at Alexandria in Egypt a man called Hero. He had a taste for mechanical pursuits, and was the inventor of a number of useful instruments which at that time were considered marvellous. In those days water-clocks were in use which indicated the time by the amount of water that flowed from one vessel to another. Hero improved these greatly, and he also invented a self-feeding wick for oil lamps, a stone-crusher, and a kind of cyclometer for measuring the distance travelled by a chariot. He was also familiar with the principle we have been discussing, for he devised an instrument called a Surveyor's Level in which it is employed. A long box provided with an opening at each end, as shown in the diagram on next page, was filled with water. The water of course stood at the same level in each tube if the box was level. If, however, the box was not level, the amount of slant could be found by measuring the difference between the heights to which the water rose in the tubes. It is said that Hero devised this instrument in view of the controversies that used to arise after the annual flooding of the Nile, because

at those times all landmarks were swept away, and men quarrelled about the boundaries of their lands. The land

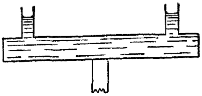


FIG. 14.

FIG. 15.

was therefore surveyed, and Hero's instrument was used in this surveying, for it is sometimes important to find when two points are on the same level. Nowadays an instrument called a theodolite is used for this purpose. (6) The spirit-level used by workmen of all kinds to find out when a surface is level illustrates still further this principle. It consists of a tube, slightly curved, nearly full of spirit. The spirit always tries to get down as far as possible, and when the tube is exactly horizontal, the bubble of air is in the middle of the tube ; otherwise it goes to one side, where, as a rule it cannot be seen because of the case that contains the tube.

Roman Conduits or Aqueducts.

The Romans were not familiar with the principle that water tends to find its own level, and their ignorance of it caused them a tremendous amount of trouble and expense. In order to supply Rome with water, they built immense conduits, several miles long, to carry the water from the hills to the city. These conduits were really high canals supported by huge arches, and built in such a manner that the water always flowed downwards. They did not know that, if the water had been led underground in pipes, it would have risen again to any level lower than the source of the water. The remains of these conduits may be seen to this day at Rome, and in some parts of the north of Africa which the Romans occupied.

Meaning of Pressure.

If you take a rectangular block weighing, say, 24 lb. and measuring $6'' \times 4'' \times 3''$, and lay it on the bench on its largest face, then it will cover 24 square inches of the bench. Thus a weight of 24 lb. will be spread over an area of 24 square inches, and, if the density is uniform, the weight on each square inch will be 1 lb. Now, if we take the pound and the square inch as our units, we say that the pressure exerted by the block on the bench is 1 lb. per square inch. If the block is now turned over

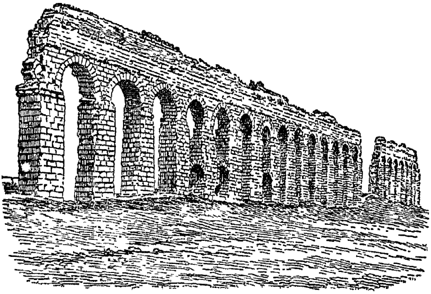


FIG. 16.—The Aqueduct of Claudius.

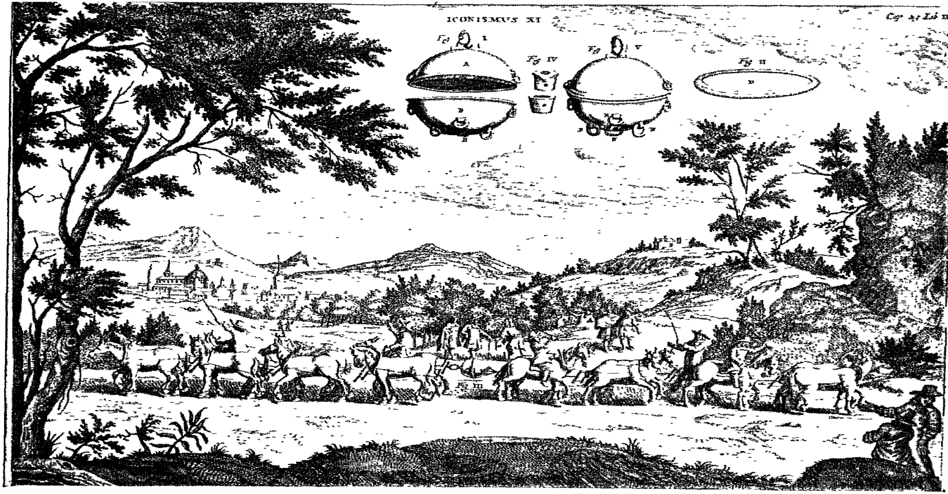
on its side, the area of the bench now covered is only 18 square inches. Of course, the weight of the block is still the same, and hence the pressure will be $1\frac{1}{3}$ lb. per square inch. Finally, if the block is made to stand on end, the area covered will be 12 square inches, and the pressure 2 lb. per square inch. The block, of course, has the same weight no matter on which face it is resting, but when it is resting on its largest face, the weight is distributed over a greater area than when it is resting on its smallest face. Thus while in both cases the total weight, or *total pressure* as it is usually called, is the same,

the weight on each square inch is different, that is, the *pressure* is different. Pressure is thus more than a mere weight or force: it is the force exerted on unit area. The total pressure is the force exerted on the whole area.

Pressure in a Liquid.

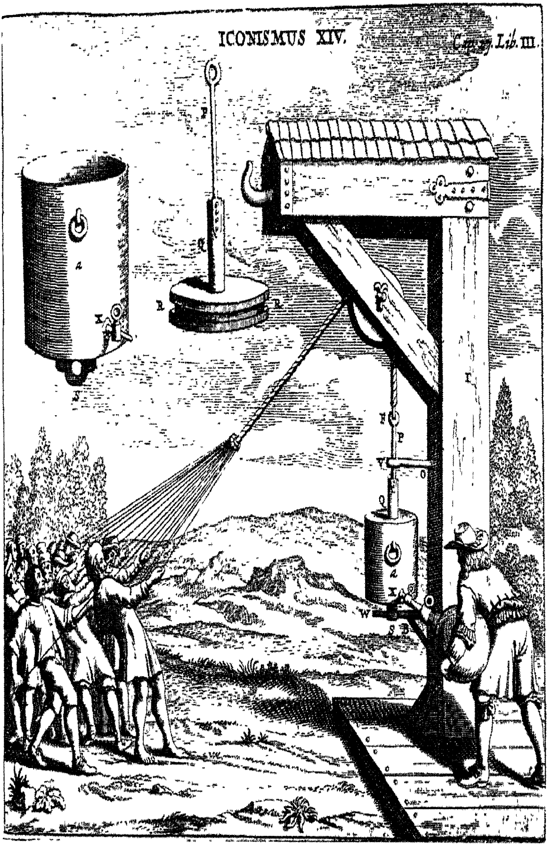
If, in playing football or some other game, you happen to fall (which you will agree is no uncommon experience), and some boys fall on top of you, you know with painful certainty when each successive boy adds himself to the human pile—the pressure on your body increases with every addition of weight. In the same way, you would expect that the deeper down a body goes into a liquid, the greater will be the pressure on that body, because the greater will be the amount of liquid pressing down on it; and this is actually the case. The pressure at any point in a liquid depends, for one thing, on the depth of that point below the surface of the liquid. Deep-sea fish swell when they are brought to the surface, because they are constructed so as to be able to withstand the great pressure in deep waters, and when that pressure is taken off by bringing the fish to the surface, the internal pressure continues, and causes them to swell.

But there is another factor to be taken into account. The pressure on the bottom of a vessel will be greater if the vessel contains water than it will be if it contains turpentine, because the density of the latter is less than that of water. If 80 cubic centimetres of water are poured into a measuring jar, the *total* pressure on the bottom of the jar will be 80 grams. If 80 cubic centimetres of turpentine are poured in, the total pressure will be only $80 \times 0{\cdot}87$ or $69{\cdot}6$ grams ($0{\cdot}87$ gram per cubic centimetre is the density of turpentine). To find the pressures on the bottom of the jar, we must now find the area of the cross-section, and divide the total pressure



GUERICKE'S MAGDEBURG HEMISPHERES EXPERIMENT.

From a contemporary drawing.



GUERICKE'S ATMOSPHERIC PRESSURE EXPERIMENT.

From a contemporary drawing.

in each case by this area. For example, suppose the area of the cross-section is 8 square centimetres, then, when the jar contains water, the pressure on the bottom will be 10 grams per square centimetre, but when the jar contains turpentine, it will be 8·7 grams per square centimetre. The pressure in the latter case is only 0·87 of the pressure in the former, and 0·87 is the number representing the density of turpentine. So we see that the pressure at a point in a liquid depends on the density of the liquid as well as on the depth of the point below the surface. In the example just given, the volume of turpentine is 80 cubic centimetres, and the cross-sectional area is 8 square centimetres; hence the height (or depth) of the liquid must be 10 centimetres, for the volume of any prism is found by multiplying the area of the cross-section by the height. The pressure of the turpentine on the bottom of the jar is 8·7 grams per square centimetre, and this number is the product of the height (10 centimetres) and the density (0·87 gram per cubic centimetre). The result in this particular case is universally true, namely, the pressure at any point in a liquid is the product of the depth of the point below the surface and the density of the liquid.

It follows from this that *at all points in the same liquid at the same level the pressure is the same.* You will find it very useful to keep this in mind.

Density by U-tube.

Arising from the general principle just stated, we have another method (and a very accurate one) for finding the density of a liquid. Water is poured into a U-tube, and then another liquid that does not mix with water (turpentine, say) is poured on top of the water. Below the point B (Fig. 17) where the two liquids meet there is only water, and below the same level D in the other limb

there is only water, and as these two columns of water just balance each other, we may neglect them, and consider only the two balancing columns AD of water and CB of turpentine. Now the pressure at the junction of the two liquids B is equal to the pressure at the same level D in the other limb of the U-tube, because these points are in the same liquid (water). Again, the pressure at D is due to the column of water AD pressing on it, and the pressure at B is due to the column of turpentine CB pressing on it. The pressure due to the turpentine column is the height CB multiplied by the density of turpentine (d); the pressure due to the water column is the height AD multiplied by the density of water, or

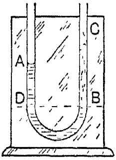


FIG. 17.

$$CB \times d = AD \times 1$$ (since density of water is 1 gram per cubic centimetre)

$$\therefore d \text{ (density of turpentine)} = \frac{AD}{CB}$$

that is, if a column of a liquid is balanced against a column of water, the density of the liquid may be found by dividing the height of the water column by the height of the liquid column.

In the case of a liquid that mixes with water, the experiment may be modified by first of all filling the bend of the U-tube with mercury. The liquid whose density is to be found is poured down one limb, and will, of course, depress the mercury in that limb. Water is then poured into the other limb, till the mercury is at exactly the same level in both limbs. The density of the liquid is found as in the previous paragraph.

Pressure of a Gas.

Since all gases have weight, it is clear that they must also exert pressure, but it is not at first sight clear how

that pressure may be measured. For example, how can the pressure of the gas supply in the laboratory be measured? How can we measure a thing we cannot see? Perhaps we could use the force of the gas issuing from the pipe to move something that we *can* see and measure; and that is just how it is done.

If a U-tube is half-filled with water, and one of the limbs connected by a piece of rubber tubing to the gas supply, and the gas turned on, the pressure of the gas will force down the water in that limb and up in the other. The difference in the levels of the water in the two limbs is a measure of the pressure of the gas, for the column of water BC is balanced by the gas.[1] The pressure of the gas is generally expressed as being equal to so many inches of water; the actual pressure, if required, can easily be calculated. This column of water BC is called, in engineering language, a "head" of water, which term is generally applied to a column of liquid supported by the pressure of a gas.

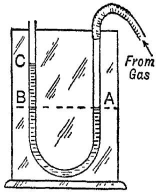


FIG. 18.

[1] The pressure of the gas balances not only the pressure due to the column of water, but also the atmospheric pressure. The column of water indicates the excess of the gas pressure over the atmospheric pressure.

CHAPTER XI

THE BAROMETER

Air exerts Pressure.

It is a very easy matter to show by a few simple experiments that air exerts pressure; but probably you do not require to perform these experiments to be convinced of the fact, for you have often walked with difficulty in the face of a high wind (which is simply air in motion), and the mere fact that you find walking difficult in these circumstances shows that pressure is being exerted against you. But that air exerts pressure is not quite so obvious when it is at rest. You have seen, however, in the laboratory that it can support water contained in a vessel the mouth of which is either under water or covered with a piece of thin cardboard; that, when air is extracted from a cylinder with a sheet of rubber stretched over one end, the rubber is pressed inwards, because the pressure inside the cylinder is less than the pressure on the outside of the rubber sheet.

Guericke's Experiments.

The historic experiment, however, was that in which a German scientist, Otto von Guericke by name, showed in dramatic fashion the enormous pressure of the air. He had a sphere or globe made of thick copper which was divided into two halves. In order to make the junction of these halves air-tight, a ring of leather soaked in wax and turpentine was inserted. Then, having joined the

two halves, he extracted the air from the inside of the globe by means of an air-pump which he himself had just invented. A tap was turned after the air had been pumped out, and thus no air was allowed to enter. He discovered that he could not now separate the two halves of the globe, even if he exerted all his strength in trying to do so ; even two men pulling against each other as hard as they could failed to pull them apart. The fame of this experiment soon spread, and in 1651 he was commanded by the German Emperor to perform it in his presence. The spectators, consisting of practically the whole Court, were astonished to find that it required the combined strength of *sixteen horses* to separate the two halves ; yet if air was allowed to enter the globe, the halves came apart quite easily.

Another experiment that Guericke performed to convince sceptics of the enormous pressure of the atmosphere was as striking as the one that has just been described. He took a cylinder in which a piston fitted tightly, and suspended the piston by means of a strong rope passing over a wheel, and to the end of the rope twenty smaller ropes were attached, each of them being held by a strong man. The piston was pulled up to the top of the cylinder, and held there by the twenty men. There was a hole in the bottom of the cylinder, and into this hole Guericke inserted the nozzle of a large globe from which the air had been extracted by means of his air-pump. When he turned the tap that had prevented air from entering the globe, air rushed from the cylinder to the vacuous globe, driven in by the pressure of the atmosphere on the piston. So great was the force with which the piston descended that the twenty men, although they exerted all their strength, were jerked violently forward.

The ancient scientists were always encountering prob-

lems which were difficult to solve. Sometimes they succeeded in solving them, sometimes they had to leave them for their successors to tackle. In some cases, we find generation after generation of scientists attacking a single problem in their endeavour to find a solution of it. Such a problem was the relation of the earth to the rest of the universe. Many were the controversies to which this question gave rise, each man who studied it giving his own version, or supporting that of somebody else. Galileo, an Italian scientist, was persecuted by the Church authorities for daring to assert that the earth revolved round the sun, and not the sun round the earth, according to the common belief. Of course we have now conclusive proof that Galileo was right.

"Nature abhors a Vacuum."

Another problem that was pursued eagerly was that of trying to produce a vacuum, that is, an entirely empty space. As far as was known, there was no vacuum in nature, and not only so, but nature would not allow one to be made. The result of all the labours of many men was contained in the statement, "Nature abhors a vacuum." It was not a very scientific statement, but it expressed in a way what was then believed to be the fact.

Suction Pump.

It was this principle that was invoked to explain the action of the common or suction pump, used for raising water from a well, a contrivance that is still used in country districts. Its construction is shown in the accompanying diagram. A is the top portion of the pipe that leads down to the water in the well. Between the pipe and the barrel C of the pump there is a valve B which can open in one way only, namely, upwards. D is a piston that fits the barrel tightly, and is made to move

up and down by the handle F. The piston is not solid there being a hole through it which is closed or opened by the valve E. When the handle is raised, the piston is pushed down, causing valve E to open and valve B to close. During the downstroke of the handle, that is, when the piston is raised, E closes and B opens. When the handle has been worked up and down several times, water is drawn into the barrel, and when the piston is raised the next time, it carries some water with it, which, on reaching the pipe G, overflows through it. Thereafter, every time the piston ascends, water flows through G.

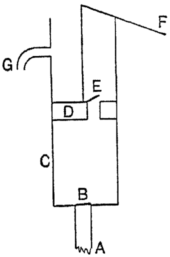


FIG. 19.

An Italian Problem.

To explain the action of the pump, it was said that when the piston was raised, no air was allowed into the barrel, and therefore it *tended* to produce a vacuum. Seeing, however, that nature "abhorred" a vacuum, water from the well rose to fill the space which would otherwise have been empty. That, of course, was quite a reasonable explanation in the light of the knowledge of the day, but there came a time when an exception to this apparently general principle was encountered. It came about in this way. The Grand Duke of Tuscany ordered a well to be dug to supply water to his palace. This was done, and it was found that the water was about 40 feet below the surface. When, however, the pump had been fitted up, no water came. One can imagine that the workmen would examine the pump to see if it was air-tight, and, finding no flaw, would try again, but still without success. The water, they found, rose to a height of about 33 feet,

but it would not rise any higher, no matter how much they worked the pump. They were at a loss to account for this, and, in their extremity, they decided to consult the eminent scientist Galileo, whose fame was at this time world-wide, if for nothing else than his invention of the telescope. But Galileo was puzzled. The only answer he could give was that nature's abhorrence of a vacuum did not extend beyond 33 feet, which, of course, was no explanation at all: it was simply stating the problem in another way. Why did nature's abhorrence not extend beyond 33 feet?

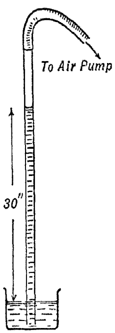


FIG 20.

The correct explanation of the rise of the water in the common pump was first given by a friend and pupil of Galileo, the now famous Torricelli, in the year 1643; but before recording Torricelli's experiment, it will be best to describe an experiment similar in some respects to the attempt to pump water from a 40-foot well. A glass tube 3 feet long or more, open at both ends, is supported in an upright position with the lower end under the surface of mercury. If the upper end is connected to an air-pump, and the air extracted from the tube, mercury will at once rise to take the place of the air which has been pumped out. At first the mercury will shoot up rapidly, but with each successive stroke of the pump the ascent of the mercury will become slower and slower, until finally it stops altogether at a height of about 30 inches. No matter how long or how quickly the pump may be worked, the mercury cannot be induced to rise any higher. This, you will see, is very similar to what happened in the case of the Italian well. Now the specific gravity of mercury is 13·6, and if 30 inches is multiplied by 13·6, the result

is 34 feet, which is practically the same height as that to which the water rose from the well. By using mercury, therefore, instead of water, the apparatus with which this problem is investigated can be kept within manageable dimensions.

Torricelli's Experiment.

It was Torricelli who first thought of using mercury in his experiments on this question, but he himself was not able to carry them out, because he could not obtain a glass tube strong enough to hold mercury. What is still called Torricelli's experiment was carried out by a friend, but Torricelli rightly receives all the credit for it, for it was done under his instructions. His friend, then, took a strong glass tube about 3 feet long, closed at one end. This tube he completely filled with mercury, or quicksilver as they called it, and, having closed the open end of the tube with his thumb, he inverted it, and placed this end beneath the surface of some more mercury contained in a basin; then he took away his thumb. The mercury immediately descended until it stood at a height of about 30 inches above the

FIG 21.—TORRICELLI.
(From an engraving by S. L.)

surface of the mercury in the basin. Why did not *all* the mercury run out ? What was keeping it up ? Torricelli had no hesitation in saying that it was the pressure of the atmosphere that balanced the column of mercury in the tube. This, said Torricelli, is the reason that water cannot be pumped from a well 40 feet deep. The column of water ascends in the pipe to such a height that its weight exactly balances the pressure of the atmosphere. In other words, the atmosphere, having weight, presses on the surface of the water in the well, and when the pressure is removed from within the pipe by raising the piston of the pump, the water in the well is forced up by the atmospheric pressure outside until the water column produces a pressure equal to that of the atmosphere. Thus was the true explanation of the action of the common pump established.

The same experiment too abolished the notion of nature's abhorrence of a vacuum, for the space at the top of the tube in Torricelli's experiment was absolutely empty. After all the strenuous efforts that had been made to produce a vacuum, this was far too simple a method for the philosophers of that time, and some of them even disputed the conclusion that the column of mercury was supported by the atmosphere. They measured the pressure of the column of mercury, and found it to be nearly 15 lb. per square inch, and they would not believe that such a rare substance as air could exert such an enormous pressure (they had not yet heard of Guericke's experiments in this connection). They thought they had finally dismissed the idea when they stated that, if it were true that the pressure of the air was about 15 lb. per square inch, then the pressure on the human body would amount to several tons. This argument, of course, is easily answered. Our bodies are so constructed that they can resist that pressure. It is a well-known fact that airmen when they ascend to

great heights are troubled with bleeding at the nose and ears. The farther one ascends into the air, the less does the pressure become, because the air becomes less dense. The pressure in the airmen's bodies, however, remains the same as it was before, and, since it has a less pressure resisting it, some of the more delicate blood vessels are burst. Though we are not conscious of the atmospheric pressure, we are made aware of it if it changes to any considerable extent.

Pascal's Experiment.

The doubts that were entertained as to Torricelli's explanation were soon set finally at rest by some experiments instituted by the celebrated Blaise Pascal whose name has already been mentioned. Having learned the details of Torricelli's experiment, he resolved to undertake further researches on the subject. If, Pascal reasoned, it is the pressure of the air that balances the column of mercury in the tube, the height of the column would be less if the experiment were performed on the summit of a mountain, because there the pressure of the air is less. Pascal induced his brother-in-law, Perier, who possessed some acquaintance with scientific instruments, to undertake the application of this test, which would prove once and for all whether Torricelli was right or not. Accordingly, in the year 1648 (the delay was caused by the usual difficulty at that time—lack of suitable glass tubes) Perier proceeded to a mountain in Auvergne, taking with him two similar glass tubes, each about 4 feet long, closed at one end. The Torricellian experiment was performed with both tubes at the foot of the hill, and the height of the mercury measured. One of the tubes was then left there, and a man was appointed to take care of it, and to note any changes that might occur during the day. Perier took the other tube, proceeded to the top of the hill, and

performed the experiment there. He found, on measuring the height of the mercury, that it was 3 inches less than it was at the foot. On descending again, he learned that there had been practically no variation in the height of the mercury in the tube he had left at the foot of the hill.

This experiment settled the controversy that had arisen as a result of Torricelli's experiment, and proved that his explanation was the correct one. At the same time, science acquired an instrument of the greatest value—the barometer. Torricelli has the double distinction of being the first to produce a vacuum, and of being the inventor of the barometer, which has become indispensable, not only in the scientific laboratory, but in everyday life. Torricelli himself quite realised the importance of what he had done ; he laid particular stress on the fact that his instrument measured the pressure of the atmosphere, which, he noticed, changed from day to day, though perhaps he did not know what those changes implied.

Why the Barometric Height varies.

Now what *does* cause the pressure of the atmosphere to change ? This question could be investigated only by patient experiment. A record was kept, covering a long period, of the height of the barometer and the state of the weather, each being recorded every day. It was found that when the weather was wet, the barometer was low, and when the weather was dry, the barometer was high. It was therefore concluded that the height of the barometer had something to do with the amount of water vapour in the air. Of course, even on a dry day, there is a certain amount of water vapour in the air. Now water vapour is less dense than air. Hence, when there is a considerable amount of water vapour mixed with the air, it makes the density of the atmosphere, and therefore its pressure, less, which causes the mercury in the barometer to fall slightly, and

stand at a lower level than it does when the air is dry. Thus the variations in the height of the barometer are accounted for.

Now the presence of water vapour in the air in considerable amount generally means that rain is imminent. For this reason, and that stated above, the barometer has come to be used for forecasting the weather. A low barometer indicates an excessive amount of water vapour, which, in turn, indicates a fall of rain in the near future. A high barometer means a comparative absence of water vapour, and therefore dry weather. But the barometer is by no means an infallible guide in weather prediction; other factors have to be taken into account. It tells us what kind of weather we shall *probably* have.

The Weather-glass.

The variations in the height of the barometer were recorded by many men, and Robert Boyle (of whom more will be said in the next chapter) was one of them. Incidentally it might be mentioned that it was Boyle who gave the barometer its name. As a result of his observations, he inserted the words "Rain," "Stormy," etc., which are still seen on the dial of the wheel barometer, showing that he quite understood the connection between the height of the barometer and the weather.

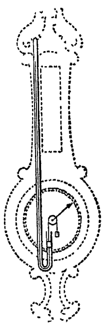


Fig. 22.—The Wheel Barometer.

The wheel barometer, or, to give it its popular name, the weather-glass, was devised by Hooke, who, by the way, invented the spirit-level, in the latter part of the seventeenth century. The diagram practically explains itself. On the surface of the mercury in the open tube there floats a piece of

glass attached to a thread which passes over a little wheel, and has another glass weight, lighter than the first, at the other end to keep it taut. To the wheel is fixed a pointer which moves round a circular scale indicating the atmospheric pressure in inches, and also the probable state of the weather in the immediate future. When the mercury rises in the barometer, the glass float falls in the open limb (seeing that it is heavier than the other weight), the pointer moves round to the right, and the rise is indicated by the pointer with the help of the scale. When the barometer falls, the mercury in the short open limb rises, and pushes up the glass float, causing the pointer to rotate in the other direction.

Heights of Mountains and Aeroplanes.

The experiment that Pascal's brother-in-law performed suggests another use to which the barometer may be put, namely, to measure the heights of mountains. It has been found that for every 900 feet a barometer is taken up from sea-level, the mercury falls 1 inch, but for greater heights this is not strictly true, as will be seen in the next chapter. If a barometer is taken down a mine, on the other hand, the mercury will rise, because the atmospheric pressure is greater. This fact can be used to find the depth of mines. The barometer is part of the necessary equipment of an aeroplane. It is by means of this instrument that an airman knows at what height he is flying.

The Water Barometer.

You may have noticed that, in all this discussion of the barometer, it has not been suggested that any liquid other than mercury might be used, and it is natural that you should ask the reason, if it has not already occurred to you. Let us imagine that we tried to use water for this purpose. The first thing to find out would be the length of tube we should require. Since mercury is 13·6 times denser than

water, the height of the water barometer will be 13·6 times the height of the mercury barometer, that is, 13·6 times 30 inches, or 34 feet. We need go no farther than this, for the length of the tube is, of itself, sufficient to rule out water as a barometer liquid. When we remember, too, that the water would freeze in winter, and that probably the tube would break (just as water pipes burst), it is seen that a water barometer is quite out of the question. Other liquids have similar disadvantages, so mercury is the only liquid that is used for this purpose.

The Aneroid Barometer.

Even a mercury barometer, however, is too clumsy for carrying about : the mercury is apt to be spilt if it is often moved. Almost exactly two hundred years after Torricelli made his famous experiment, a Frenchman, Vidi by name, invented an ingenious and delicate instrument called an aneroid barometer : the word "aneroid" means "no liquid," and the name indicates that no liquid is used in this barometer. It consists of a hollow metal cylinder from which the air has been partially extracted, and which has thin flexible sides which bend inwards or outwards according to the pressure of the atmosphere. The motions of the sides of the cylinder are communicated by means of levers to a pointer which moves round a dial similar to that of a wheel barometer. The great advantages of an aneroid barometer are its compactness and its portability. Such barometers are made of various sizes, and the smallest, which is about the size of a watch, gives quite reliable results. It is, of course, an aneroid barometer that is used

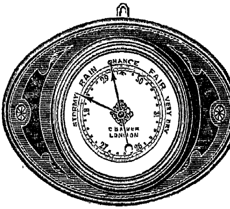


FIG. 23.—Aneroid Barometer.

in an aeroplane to indicate its height; in fact, for all purposes that necessitate moving the barometer about from place to place, a mercury barometer would be awkward and clumsy, if not actually useless.

The Fortin Barometer.

When the pressure of the atmosphere is required very accurately, a Fortin barometer is used, where a device is employed to bring the mercury in the cistern always to the same level before taking a reading. The bottom of the cistern is made of leather, and can be raised or lowered at will by means of a screw, the constant level being indicated by a small ivory point (see Fig. 24).

FIG. 24.

The Barograph.

It is not always possible or convenient to take barometer readings as often as is sometimes required. This difficulty was overcome by the invention of the barograph, which is a self-recording barometer. The usual form consists of an aneroid barometer, but the pointer, instead of moving round a dial, is made to touch a strip of paper wrapped round a revolving drum or cylinder. This cylinder goes by clockwork, and the pointer is provided with a pen which moves over the paper and leaves there a record of the changes in atmo spheric pressure. The paper is so marked that the pressure at any hour can easily be found.

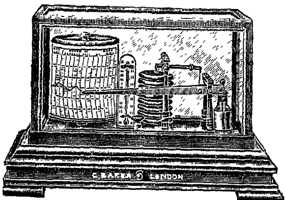


FIG. 25.—The Barograph.

PASCAL.

From the engraving by Edelinck.

THE HON. ROBERT BOYLE, F.R.S.

From a copy of the portrait by F. Kerseboom in the National Portrait Gallery.

CHAPTER XII

BOYLE'S LAW

Compression of Gases.

If you take a good bicycle inflater or a syringe, pull out the handle, put your finger on the nozzle, and then try to push in the handle, you will find some difficulty in doing so. You will succeed in pushing it only a short distance. The facts that your finger is on the nozzle, and that the barrel is full of air, prevent the piston from getting to the end of the barrel. But notice that you *can* push in the handle a short distance. What does that mean? It means that the air in the barrel can be compressed or squeezed into smaller space. Now this is a property that is practically absent from solids and liquids. A piece of iron cannot be made to occupy a smaller space, nor can a quantity of water, at least, not to an appreciable extent. Small changes in volume do occur under great pressure, but they are so small that they can be neglected at this stage. Gases, however, by the application of even small pressures can be decreased in volume to a measurable extent.

Boyle and "the Spring of the Air."

If, when you have pushed in the piston of the inflater keeping your finger on the nozzle, you suddenly release the handle, it will spring back to its original position. It was for this reason that the man who first investigated this property called it the "spring of the air," because the

air seemed to him to act in a manner somewhat similar to the action of a spring, which can be stretched and compressed. This man was Robert Boyle, who lived in the seventeenth century, which you may have noticed was a very profitable century as far as science is concerned. He was ardently devoted to science, and, although he was the son of an earl, he would not accept a peerage, but preferred to employ the advantages of his high birth and great fortune in promoting the interests of scientific study. The first of his many and varied contributions to science was a book entitled *New Experiments Physico-Mechanical touching the Spring of the Air and its Effects*. In one of the experiments described in this book, he employed a glass U-tube with a short closed limb, which has come to be known as a Boyle's Law tube. By pouring mercury into the tube, a certain amount of air was imprisoned in the short limb, and, on adding more mercury, he found that the volume of the enclosed air became less because of the increased pressure due to the extra mercury. Boyle's aim, however, was not merely to show that the volume of air decreased when the pressure on it was increased, but to try to find a quantitative relation between the pressure and the volume, that is, to find *by how much* the volume decreased when the pressure was increased by a certain amount.

Boyle's Law.

In order to understand Boyle's measurements, we must recall a principle which we discovered in dealing with the pressure in a liquid, namely: at all points in the same liquid at the same level the pressure is the same. In Fig. 26 the pressure at the point D, the surface of the mercury in the open limb, is the atmospheric pressure. At the point C (which is at the same level as B, the surface of the mercury in the closed limb) the pressure is equal to

the pressure at D together with the pressure due to the column of mercury CD. The pressure at C is equal to the pressure at B, because they are in the same liquid and at the same level, and this gives the pressure on the enclosed air. Thus the pressure on the air can be measured by finding the pressure due to the column of mercury CD and adding the atmospheric pressure. The pressure, of course, can be changed simply by pouring in more mercury.

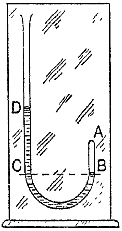


Fig. 26.

By proceeding in this way, Boyle obtained two series of numbers, one representing the different pressures on the enclosed air, and the other the corresponding volumes of the air. On comparing these sets of numbers, he found that the one set was inversely proportional to the other, that is, as the pressure increased, the volume of the air decreased *at the same rate*. It was afterwards discovered that all gases, under certain conditions (see p. 106), follow the same rule. This fact is known as Boyle's law, which may be stated thus: The volume of a gas is inversely proportional to its pressure. A French scientist, Mariotte, made the same discovery, probably independently, a few years after Boyle made it, and to this day it is referred to in France as Mariotte's law.

Inverse Proportion.

It might be advisable to explain more fully what is meant by inverse proportion by taking a familiar example of it. Suppose that 30 men are set to build a wall, and that they can finish it in 20 days; then it is obvious that if only 15 men were employed they would take 40 days to build the wall; if only 10 men were available, they would take 60 days,

and so on. Let us set it down in the form of a table, thus:

10	men take	60	days
15	,, ,,	40	,,
20	,, ,,	30	,,
40	,, ,,	15	,,
60	,, ,,	10	,,

As the number of men is increased the time taken is decreased at the same rate, or, the number of men is inversely proportional to the time taken. If the number of men is doubled, the time is halved ; if one-third of the number of men is taken, the time is trebled. Similarly, if the volume of a gas is doubled, the pressure is halved, if the volume is reduced to one-third, the pressure is trebled. If you put your finger on the nozzle of a bicycle inflater, and push the piston in half-way, then the volume of the air inside is halved, and therefore the pressure must be double what it was at first. The pressure at first was that of the atmosphere, or 14·7 lb. per square inch ; hence when the piston is pushed in half-way, the pressure on the air must be 29·4 lb. per square inch. Note that the products of the numbers in inverse proportion are all the same ; for example, the products in the above table are all 600. This is the usual test applied to numbers to ascertain if they are in inverse proportion.

Meaning of "Law" in Science.

As this is the first occasion on which the word "law" has been mentioned in its scientific sense, it will be well to say a few words about it. You know that the country is governed by Parliament, a body of men who meet in London and discuss matters concerning the welfare of the nation, and pass certain laws which every one must obey. In cases of disobedience to any law, or, as we say, when a law is broken, penalties are inflicted upon the offender

which vary according to the seriousness of the offence. Now a law in the scientific sense is totally different: it has nothing in common with civil law. A scientific law is simply a general statement of a fact. Boyle's law, for instance, simply states that if the pressure on a gas is increased the volume will be decreased at the same rate. There is no compulsion about it: no punishment is meted out to a gas which fails to conform to the law; in fact, under certain conditions, gases do *not* conform to it. One sometimes hears people talk loosely of gases "obeying" Boyle's law, but that is entirely misleading. This law states how gases *do* behave, not how they *ought* to behave. If Boyle had never discovered his law, the volume of a gas would have been affected by an increase of pressure in exactly the same way as we now know it to be affected.

Homogeneous Atmosphere.

From the fact that air is compressible, it follows that, near the surface of the earth, the air will be more dense than it is some distance away from the earth, for each successive layer of air presses, by reason of its own weight, on the layer below it, and makes it occupy less space than it would otherwise do. It was stated in the previous chapter that, for a difference of 900 feet in altitude, the difference in the barometric height is 1 inch, but that that was not uniformly true. The reason for the latter part of the statement will now be apparent. The density, and therefore the pressure, decreases with increase of altitude. For the first rise of 900 feet, the fall of the barometer is 1 inch, but, for the barometer to fall another inch, there must be a rise of more than 900 feet. One would think that, by finding out the exact increase in altitude which would produce each successive fall of 1 inch, it could be calculated what rise would cause the barometric height to vanish altogether, that is, how high the atmo-

sphere extends. It is not quite so simple as this, however, for even our highest mountains are not nearly high enough for this purpose, and besides, other considerations enter which make it impossible to arrive at a correct conclusion. Opinions vary as to how high the atmosphere reaches: some put it at 40 miles, some as high as 200 miles. For some purposes, it is convenient to know how high the atmosphere *would* reach if it had the same density all through as it has at the surface of the earth. This is quite a simple calculation: it amounts to finding the height of a column of air of density 0·00129 gram per cubic centimetre which will have the same pressure as a column of mercury 76 centimetres high whose density is 13·6 grams per cubic centimetre. If this is worked out, the result is found to be about 8 kilometres, that is, about 5 miles. This is called the height of "the homogeneous atmosphere." Thus we may say that the pressure of the atmosphere on the earth's surface is the same as it would be if the earth were surrounded by an atmosphere about 5 miles high having the same density throughout as it has at the surface of the earth.

CHAPTER XIII

HYDROSTATIC MACHINES

The Bramah Press.

Pascal, with whose name you are now familiar, discovered that if pressure is brought to bear on any part of a liquid or a gas, then it is transmitted through the liquid or gas equally in all directions. If you take a large U-tube with unequal limbs of cross-section, say, 1 square inch and 5 square inches respectively, pour in some water, and fit both limbs with tight-fitting pistons, then if one piston is pushed down the other will rise. If a weight of 1 lb. is placed on the smaller piston, that creates a pressure of 1 lb. per square inch in the water, and that pressure is transmitted through the water to the other piston. But the area of the other piston is 5 square inches, hence the *total* pressure upwards on the piston will be 5 lb., that is, a pressure of 1 lb. per square inch. Thus, to keep the two pistons at the same level, a weight of 1 lb. on the smaller piston will require a weight of 5 lb. on the larger.

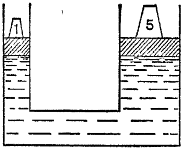


FIG. 27.

This fact is made use of in the hydraulic press, often called the Bramah press after its inventor, who lived in London at the end of the eighteenth century, and by his invention laid the foundation of a new branch of engineer-

ing. It is employed in lifts, for riveting steel plates, in boring tunnels, and for many other purposes.

Hare's Apparatus.

It will be remembered that the U-tube may be used to find the density of a liquid; but it is not always convenient to use liquids that do not mix in making this determination. When the liquids mix, mercury may be used to separate them; but mercury is expensive, and when the densities of different liquids have to be found, this method is a long one. These difficulties are overcome if Hare's Apparatus is used. It will be seen from the diagram that this instrument is simply an inverted U-tube with a tube used as a mouthpiece connected to the bend. The liquid whose density is to be found is put into a vessel and placed so that the end of one limb of the apparatus dips under the surface of the liquid. Another vessel full of water is placed in a similar position under the other limb. Air is sucked out of the tube through the mouthpiece, thus diminishing the pressure inside the tube. The pressure of the atmosphere then forces the liquids to rise in both limbs, but not to the same height, because the liquids have different densities. The density of the liquid is obtained in the same way as by the U-tube, namely, by dividing the height of the water column by the height of the liquid column.

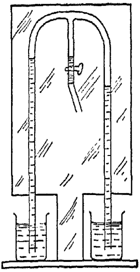


FIG. 28.

The Siphon.

The siphon consists of a bent tube, one limb being longer than the other. If the tube is filled with water, and the shorter limb placed in a vessel of water, then water will

flow through the tube until the level of the water in the vessel comes to the end of the tube. This gives a very simple method of transferring a liquid from one vessel to another. The pressure on the surface of the water in the vessel is equal to that of the atmosphere. The pressure at A within the tube (Fig. 29) is the same, seeing that it is at the same level. The pressure at B is equal to the pressure at A minus the pressure due to the column of water AB; and this pressure is tending to push a particle of water X from left to right. The pressure at D is equal to that of the atmosphere. The pressure at C is equal to the pressure at D minus the pressure due to the column of water CD; and this pressure is tending to push the particle X from right to left. Which of those two pressures is the greater? Obviously the first, as long as CD is greater than AB. Hence the water moves from left to right, and the water is transferred from the one vessel to the other. The one condition for the working of the siphon is that AB should be less than 34 feet.

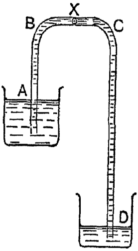


FIG. 29.

The Force-Pump.

For driving water to high levels, a force-pump is required which differs from the common or suction pump in that the piston is solid, and the second valve is situated in the delivery pipe (see Fig. 30*a*). Its working is similar to that of the common pump. Water is forced into the delivery pipe with every downstroke of the piston. The height to which the water may be forced depends only on the force applied to the piston and the strength of the pump.

For some purposes, a continuous stream of water is required When this is the case, an air-chamber is fitted

to the pump (Fig 30*b*). At each downstroke, the pressure caused by the descent of the piston forces some water into

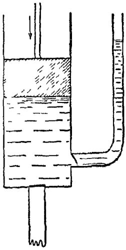


Fig. 30*a*.

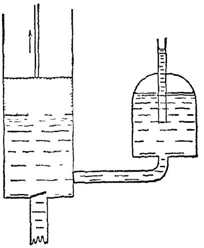


Fig. 30*b*.

the air-chamber, compressing the air in it During the upstroke, the pressure is released, and the air expands, driving water up the delivery tube Thus a continuous stream of water is kept up. This arrangement is used in fire-engines.

The Cartesian Diver.

A simple, amusing, and at the same time instructive experiment may be performed as follows. A small bulb is blown at the end of a piece of narrow glass tubing and the tube is cut about half an inch from the bulb. The bulb must be of such a size that it will float when placed in water. Water is introduced into the bulb till it just floats below the surface, and then it is placed in a bottle. If now a well-fitting cork is put in the neck of the bottle and pushed down, the bulb will sink to the bottom. When the cork is released, the bulb will rise

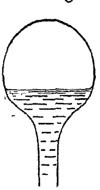


Fig. 31.

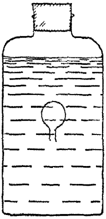


Fig. 32.

again to the surface. Let us try to find out the reason for this. When the cork is pressed down, the pressure inside the bottle is increased, and this increase of pressure is transmitted to all parts of the water. The air in the bulb receives this increase of pressure, and, of course, its volume is decreased, with the result that more water enters the bulb. The average density of the bulb is thus increased, and it sinks. When the cork is released, the opposite happens. Sometimes a grotesque figure of some kind is attached to the bulb. Descartes, a French mathematician and philosopher, suggested this curiosity, so it is usually called the Cartesian Diver. The Bottle Imp is another of its names.

CHAPTER XIV

MEASUREMENT OF ANGLES

What is an Angle ?

What is an angle ? Everybody knows what an angle is, but it is not a very easy matter to define it. We might say that, when two straight lines meet at a point, they are said to form an angle, but that is not really a definition. We need not attempt a strict definition, seeing that there is no doubt as to what is meant by an angle, but we might consider it in this way : if you lay a pair of dividers on the bench, and, holding one arm of the dividers firmly with one hand, pull the other out, then, as long as you keep pulling, the direction of that arm will change, and the angle between the arms will measure the change of direction, or the amount of turning round the pivot of the dividers.

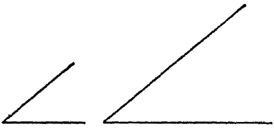


FIG. 33.

One point to remember is that the size of an angle has nothing whatever to do with the length of the arms. The two angles shown in Fig. 33 are exactly the same size, though the arms of the second are about twice as long as those of the first. The angle is the slope or inclination of one arm to the other.

How then can we compare two angles as to their size, if not by the length of their arms ? The simplest means of doing so is to lay one on top of the other, so that their vertices coincide, and one arm of the one lies along one arm

of the other. If then the second arm of the one lies along the second arm of the other, the angles are equal; if not, they are unequal.

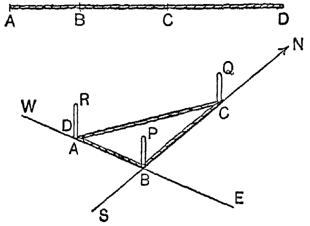
Unit of Measurement.

This is obviously a cumbersome method of comparing angles. To compare two lines, we do not measure one by laying the other on the top of it, but measure each separately by means of a ruler. So, just as we require units for the measurement of lines, volumes, weights, etc., we must have a unit for measuring angles. The unit was fixed for us somewhere about three thousand years ago by the Babylonians, and it has not been altered since then. This early race took as their unit angle the angle in an equilateral triangle, and all other angles were compared with it. They found, however, that smaller divisions were necessary, and divided this angle into sixty equal parts. This is how we obtained degrees for the measurement of angles. But why did they choose the number 60? Well, the reason is that they always used this number as the common denominator of fractions, much in the same way as we use the number 10 as the denominator of all decimal fractions. The Romans used the number 12 in the same way. It thus came quite naturally to the Babylonians to divide the angle into 60 equal parts. They then went on and divided the degree into 60 minutes, and the minute into 60 seconds. It is also said that the number 60 was chosen because it gave 360 degrees in the complete revolution, and so was the same as the number of days in a year, which was taken at that time to be three hundred and sixty, that is, twelve months of thirty days each.

Egyptian "Rope-fasteners."

The Egyptians employed a very interesting method for obtaining a right angle. They were very particular about

the direction in which their temples faced, and had therefore to obtain with accuracy a north and south line, and an east and west line. The first was easily obtained by observing the points on the horizon where the sun or a star rose and set. Drawing lines in the direction of those points, and taking a line midway between those lines, they obtained the north and south line. The east and west line was then at right angles to this. To lay down this other line, professional "rope-fasteners" were employed. Those men used a rope ABCD (Fig. 34) which had marks or knots at B and C so that the whole rope was divided in the ratio of 3 : 4 : 5. They inserted two pegs P and Q (Fig. 35) in the north and south line, and laid the rope along the same line, so that the mark B was exactly at the peg P, and the mark C exactly at the peg Q. Then, taking the two ends A and D of the rope, they stretched the rope tight, and brought the two ends together, marking the place with a peg R. The direction PR was then east and west. Those of you who know the Theorem of Pythagoras in geometry will understand why the angle RPQ is a right angle.



FIGS. 34 AND 35.

Nowadays, we have various instruments that can be used in the construction and measurement of angles: protractor, compasses, set-square, and others which we shall speak about in the next chapter.

Direction.

It was said above that an angle measures the change of direction of a line which rotates from one position to

another. Sometimes, however, we take into account a change of direction without measuring the change in degrees. If some one asks you the way to a certain place, you direct him by telling him to take the first turning on the left, and then the second on the right. "Right" and "left," however, are meaningless if he has lost himself on a moorland, and wishes to get back to the village. You might then direct him by means of landmarks, telling him to make for the windmill, and, on arriving there, to look for a clump of trees where he would find the road that would lead him to the village. But at night, even this would not

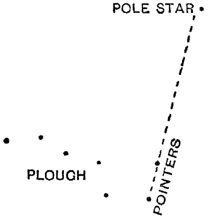


FIG. 36.

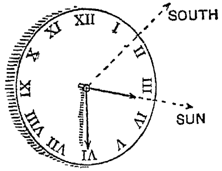


FIG. 37.

be sufficient, and recourse would have to be had to the stars. Most boys know how to find the Pole Star from the pointers of the "Plough," or "Great Bear," as that constellation is generally called (Fig. 36).

Again, every boy scout can find north and south by means of a watch when the sun is shining. If the hour hand of the watch is pointed in the direction of the sun, south will lie half-way between the hour hand and XII. If yours were a twenty-four hour watch, then the hour hand would make one revolution while the sun also apparently made one revolution. In that case south would be in the direction of XII. In the ordinary watch, the hour hand makes two revolutions while the sun apparently

makes one. Hence south is in the direction midway between the hour hand and XII.

The Compass.

All these devices fail, however, under unfavourable conditions, such as foggy weather or a cloudy night. How does the mariner steer his ship in safety in those circumstances? He uses a compass. As far back as four thousand years ago, we are told, the Chinese discovered that a bar of magnetic iron, when left free to move, always came to rest in the same position, one end pointing north-

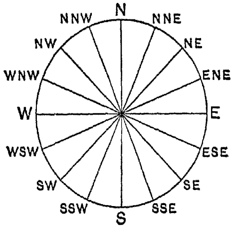


FIG. 38.

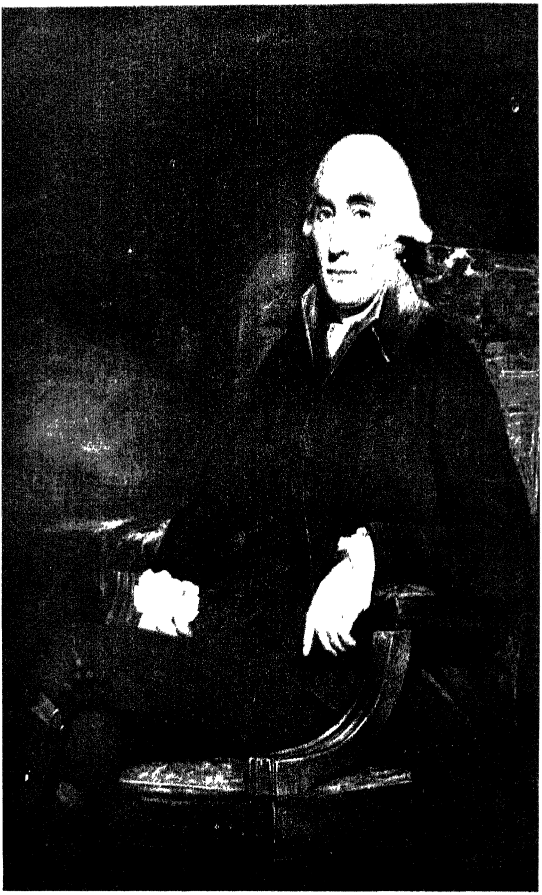
wards, the other southwards. At first, they arranged matters so that the bar would float on water, probably by placing it on a piece of thin wood, but as this was not easily carried about, they came to mount it on a pivot. The Arabs, who were great traders, got the idea from the Chinese during their travels, and it was through the Arabs that the compass was introduced into Europe. It has, of course, been immensely improved, and now a mariner's compass is a very complicated instrument; but the principle involved of the north-pointing magnetic needle is the same.

Fig. 38 shows the points of the compass. The four points N, S, E, W are called the cardinal points. The angle be-

GALILEO.

From a replica of the statue by Eugenio Rados in the Science Museum, S. Kensington.

(By kind permission of the Director.)



Professor JOSEPH BLACK, M.D.

From the portrait by Sir Henry Raeburn.

tween N and NW is $45°$, between N and NNW is $22\frac{1}{2}°$, between N and N by W (half-way between N and NNW) is $11\frac{1}{4}°$; and similarly for the other points. We can thus find the angle between any two points viewed from a third point if we know their directions by the compass taken from that point. [The direction of an object from a certain point as given by the compass is called its bearing from that point.] If you are walking along a road, and notice that a certain object is in the direction SW from you, and some time later that it is in the direction W by N, then your change of direction will be $45° + 11\frac{1}{4}°$, or $56\frac{1}{4}°$.

CHAPTER XV

SURVEYING

(1)

How Surveying began.

Every schoolboy knows that the river Nile in Egypt used to overflow its banks once every year. It does not do so now, because the water that would cause it to overflow is collected by means of dams and is then distributed in such a manner that no damage is done. Now this annual inundation of the land on either side of the river went on for many centuries, in fact, from as far back as we have any historical record. When the river subsided, it left behind it a layer of very fertile mud, without which Egyptian farming could not have existed. In times which are almost, if not quite, prehistoric, the primitive farmers naturally chose to settle near the banks of the Nile, as being the only possible place for raising crops, and the boundary of each man's land was indicated by landmarks. Now when the Nile came down in flood, it often happened that those landmarks were swept entirely away, leaving absolutely no trace. In such circumstances, it was just in accordance with human nature as we know it, that endless quarrelling should arise between men whose lands adjoined, as to what were the correct positions of the landmarks, and year after year fresh quarrels arose which were very disturbing to those concerned. At last, however, somebody had a brilliant idea: Why should not every man's land be measured? There would then be no difficulty in assigning to each man his proper amount of

land after the annual flooding. You must remember that we are now speaking about very early times, and

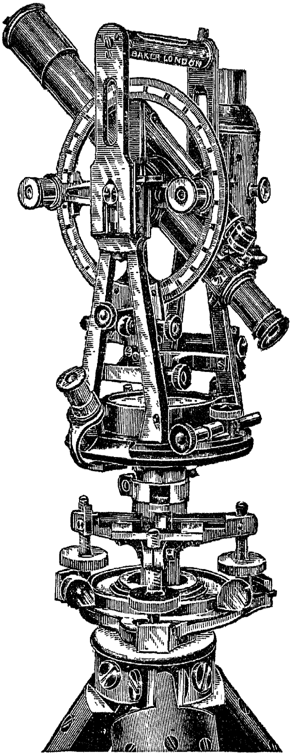


FIG. 39.—The Theodolite.

that the idea of measurement in any connection was quite a new one. Once the idea had taken root, however,

gradually means of carrying it out were devised, and land-surveying, as we now call it, came into being, and began to be practised among the Egyptians. Incidentally we might mention that this was also the origin of geometry, as the name itself indicates.

Nowadays, surveying is extensively carried on, and surveyors have many instruments and appliances at their disposal which would have made the work of the ancient Egyptians not only much easier, but also much more accurate. Nevertheless, in those days, there were not lacking men of inventive genius, and, as we mentioned in Chapter X., Hero of Alexandria devised a simple but useful surveyor's level which served its purpose very well, but whose place has now been taken by the theodolite.

The Theodolite.

The theodolite consists essentially of a sighting rod which can rotate on a vertical axis, and also on a horizontal axis, both movements being capable of measurement by means of accurately divided scales. The instrument stands on a tripod, and carries a small spirit-level to indicate when it is horizontal. It can be used (1) to find the difference in direction (angle ACB in Fig. 40) between two points A and B in the horizontal plane viewed from a third point C, or (2) to find the angle of elevation (angle ACB, Fig. 41) of any high point A.

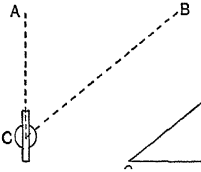


FIG. 40.

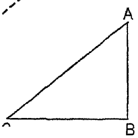


FIG. 41.

The Sextant.

Fig. 42 shows the essential parts of the sextant. As its name implies, it is in shape the sixth part of a circle.

As first used by John Hodley of London, it was a quarter of a circle, and was called a quadrant. The principle of the sextant is that two objects B and D are viewed simultaneously, one B directly, the other D reflected in a mirror, the movable arm being adjusted till both objects are seen.

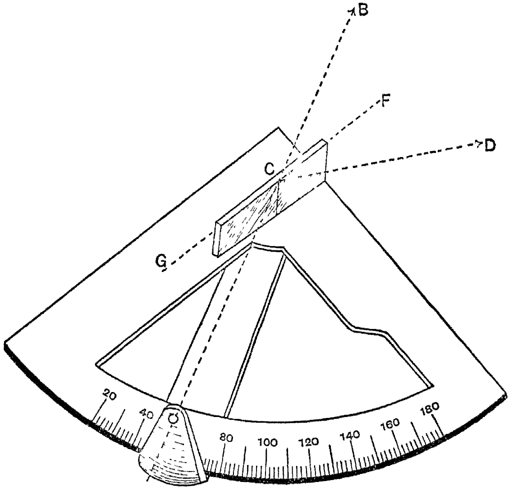


FIG. 42.

A slight knowledge of the laws of light (which branch of physics you will study later) enables us to find the angle required. As a matter of fact, the angle is simply read off from the instrument. The sextant, since it is held in the hands when being used, is specially useful at sea, where it is often not possible to obtain stable conditions, which are necessary for the use of the theodolite. The latter in-

strument, however, is the one that is almost invariably used for land-surveying.

(2)

The Plane-table.

For a rough survey where great accuracy is not required, the plane-table is very useful. It consists of a drawing-board, mounted on a tripod, and having a sheet of paper pinned on to it. A ruler on which two sights have been fastened serves as a sight-rule. Suppose, for example, that a field ABCDE is to be surveyed and drawn to scale, but that it will be sufficient if it is only approximately correct. A suitable base-line XY is first chosen, the

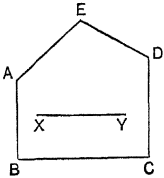


FIG. 43.

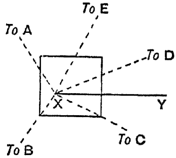


FIG. 44.

plane-table set up at X, and a north and south line drawn on the paper, using a compass. The base-line, of course, might be one of the sides of the field if it was suitable. A point X is marked on the paper immediately above the chosen point X on the ground, a plumb-line being used for this purpose. One end of the sight-rule is then placed at X, Y is sighted, and the line XY drawn. If all the points A, B, C, D, E are visible from A, each is sighted in turn, and lines drawn as shown in Fig. 44, the square representing the drawing-board, and the lines being continued beyond it for the sake of clearness. The plane-table is then removed to Y, adjusted to its proper position by the compass, and the same process repeated there.

The intersection of each pair of lines directed to the same point gives the position of that point. The points may then be joined up, and the figure is complete. If the point E, say, is not visible from X, but is visible from A and D, then the plane-table may be taken to A and D

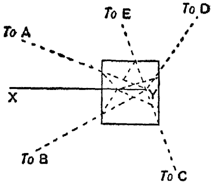


FIG. 45.

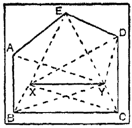


FIG. 46.

after these points are fixed on the plan, set up correctly, and the point E found by sighting from A and D.

This method of surveying is sometimes used in war to make a hurried reconnaissance of a district after an advance. Often a prismatic compass, which has degrees marked on it as well as the usual directions, is used in making such a reconnaissance, in which case the method is more akin to that described in the next paragraph.

Triangulation.

Surveying on a large scale is carried out by the method of triangulation, using a theodolite like that shown in Fig. 39, whose sighting rod is a telescope in order that distant points may be seen. The drawing is not made at the same time as the observations are taken: the various measurements are carefully noted down, and the drawing made afterwards from those measurements. The survey may be made from a single base-line, as was done above in using the plane-table. In that case, instead of sighting the various points A, B, C, D, E and drawing in their directions, the points are sighted, and the

angles read off from the horizontal scale of the theodolite. For each point a triangle can be drawn, since the base and the base angles are known, the resulting plan being the same as that obtained by the plane-table, only more accurate.

In surveying a large tract of land such as a whole country, it is obviously impossible to work from a single base-line. In that case, the base-line is successively altered according to a definite plan. Let us suppose, for example, that ABCD represents a large piece of land to be surveyed. The first base-line might be AB. This would be measured accurately, and then some point E would be chosen which was visible from both A and B. The angles EAB and EBA would be measured, using a theodolite, and from those measurements the triangle EAB could be drawn. The line EA would next be chosen as the new base-line (which would not require to be measured, since its length could be found from the plan if necessary). The theodolite would be placed at A and E, and the angles DAE and DEA would be measured. The next base-line would be DE, and the point C could be found as before. The work could be stopped there and BC joined to complete the plan, but it would be advisable to make observations of B from CE as base-line to serve as a check to the rest of the work.

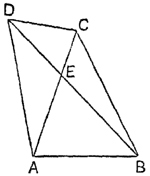


FIG. 47.

This method can be carried out very accurately with a good theodolite, and is used in the making of very accurate maps.

(3)

Measurement of Heights.

History relates that Thales, the Father of Geometry, as he is sometimes called, who lived about 600 B.C., measured

the height of the Egyptian pyramids. He did it in this way. He waited one sunny afternoon till the length of his shadow was equal to his own height, then, measuring the length of the shadow of the pyramid, he said that that was the height of the pyramid—a very simple method, but one which, we are told, astonished the spectators. It is not always convenient, however, to wait till the sun is in a particular position before making an observation of this kind, and a knowledge of the properties of similar triangles makes it quite unnecessary. The length of the shadow of a pole 3 yards long is, at any time of the day, three times the length of the shadow of a pole 1 yard long. If, therefore, we know the length of one pole, and

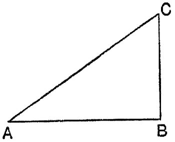


FIG. 48.

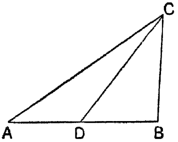


FIG. 49.

the length of the two shadows, we can calculate the length of the other pole by simple proportion. This principle can be applied to finding heights under suitable conditions.

The theodolite may also be used in measuring heights. Suppose BC to represent a flagstaff. A theodolite is placed at A, and the angle of elevation BAC measured. If the distance AB is also measured, a drawing can be made to scale and BC measured.

It may happen, however, that the foot of an object is inaccessible, and then the distance AB cannot be measured. When that is the case, the difficulty may be overcome by taking a point D in line with A and B, and at a measured distance from A, and measuring the angles CDB and CAD

with the theodolite. The triangle ADC can then be drawn to scale, AD produced, and CB drawn perpendicular to AD, and BC measured as before. In both cases the height of the theodolite above the ground must be taken into account.

Levelling.

If it is desired to measure the difference of level between two points on a hillside, the method of levelling may be used. The theodolite is set up at a convenient place between the two points, and adjusted so that the sighting

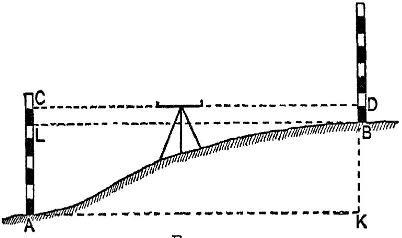


FIG. 50.

rod is level, that is, pointing to zero on the vertical scale. A levelling staff marked in feet and inches is then placed vertically at one of the points, and the reading on it taken by the theodolite. The staff is then transferred to the other point, and the reading taken. The difference of the two readings gives the difference in level of the two points. It was for this purpose that Hero's surveyor's level was used, but the fact that it consisted of an open vessel filled with water made it awkward and inconvenient for work of this kind.

PART II.—HEAT

CHAPTER XVI

THE THERMOMETER

Science in Seventeenth Century.

You may have noticed, from what has been said in the preceding chapters, that the seventeenth century was a very important one as far as science is concerned. Men like Galileo and Torricelli in Italy, Guericke in Germany, Pascal in France, and Boyle and Newton in England, by their inventive genius and their careful investigations, increased the scope and usefulness of science to an enormous extent. The centuries preceding this one, generally called the Middle Ages, had been barren scientifically, owing largely to the fact that the statements of ancient writers were accepted without being brought to the test of experiment; and, seeing that some of those statements turned out to be entirely wrong, it is obvious that no progress would be made as long as men's minds were in this servile state.

Reason for late Entry of Science of Heat.

It is noteworthy too that, during the seventeenth century, not only were men daring to contradict Aristotle by resorting to experimental evidence, but they were also improving such instruments as they possessed, and inventing other instruments previously unknown, in order to make their experiments more accurate and conclusive. Such new inventions were the telescope, the air-pump, and

the barometer, each of which brought to light facts which were entirely new, and most of which had not been even vaguely guessed at. Another instrument whose invention belongs to this period (though it was not perfected till the next century) must now be mentioned, namely, the thermometer. Heat, as a branch of science, did not emerge till the eighteenth century. Why was this? Countless ages ago, primitive men had produced fire by rubbing together two pieces of wood, or by striking one piece of flint against another, and, ever since that time, the phenomenon of heat had been familiar to everybody. It entered into everyday life in domestic cooking, in industry, and even science itself made use of heat without making serious inquiries as to its nature, and how it could be measured. If any one had taken the trouble to collect all the facts known about heat, a numerous and important collection would have been formed. Even then, facts alone do not make up science; the facts must be studied, and expressed in general principles or laws, and as a rule these laws are arrived at only after careful measurement. It is just here that we find the explanation of the late entry of heat into the field of science: it had waited for ages for its measuring instrument. Can you imagine general physics without a ruler, without a balance, without a measuring jar? Of course it would be impossible. No progress can be made in science without measurement. This remark, or one similar to it, was made in the first chapter, and here we see its truth borne out. Before men could know any but the most obvious facts about heat, they had to be able to measure it and its effects.

Galileo's Thermometer.

It is not quite certain who it was who made the first thermometer, but it is generally agreed that the honour of its invention is due to none other than the famous Galileo

in 1593. We are told that he took a glass bulb about the size of a hen's egg, with a long glass stem having the thickness of a straw which dipped into water contained in a flask Having warmed the bulb with his hand, thus expelling some air, and allowed it to cool again, water rose in the stem, driven in by the pressure of the atmosphere, when the air in the bulb contracted. You will recognise this as the apparatus used to show you that a gas expands when heated and contracts when cooled. If the air in the bulb is heated, it will expand, and so force down the level of the water in the stem; in cold weather it will contract, and the level of the water will rise. Hence, by noting the level of the water in the stem, changes in the hotness of the air in the bulb will be recorded. This is called an air-thermometer, because it is the expansion and contraction of air that is used to indicate changes of hotness. Notice that the word "hotness" is used, and not "heat." The thermometer (despite its name) does not measure the amount of heat in a body, but the hotness of it, or, to call it by its proper name, the temperature of it.

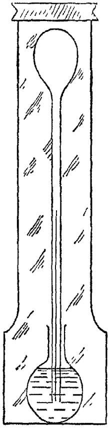


FIG. 51.

There were several objections to Galileo's thermometer, the greatest of which was the fact that the level of the water in the stem depended, not only on the temperature of the air in the bulb, but also on the pressure of the atmosphere; in fact, it acted like a combination of a thermometer and a barometer, and since it tried, as it were, to do two things at once, it did neither satisfactorily Besides this objection, there was the difficulty that any marks made on the stem to indicate differences of temperature were purely arbitrary, that is, they

were not made on any principle, so that no two thermometers could be exactly alike; a certain temperature indicated by one would be indicated by a different number on another. Thus, although an attempt had been made to provide science with a measuring instrument for heat, it was as yet quite useless for practical purposes.

Jean Rey's Improvement.

The first improvement in the thermometer was made by a French doctor, Jean Rey. What he did was simply to invert Galileo's bulb and stem, and fill the bulb with water so that it rose in the stem. In this case, differences of temperature were indicated by the expansion and contraction of water instead of air, as in the air-thermometer. This overcame the difficulty of the atmospheric pressure affecting the level of the water, but it was open to another objection. You know that the heat of the sun, or even the wind, dries up the roads after rain has fallen. In the same way, the water in the stem dried up, and so the temperatures indicated by Rey's instrument were lower than they ought to have been. Besides, the water froze in winter, and, of course, when that happened the thermometer was useless.

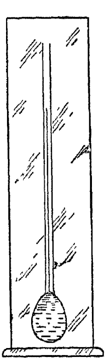


FIG. 52.

Leopold de Medici.

Both these drawbacks were overcome by one of Galileo's pupils, Leopold de Medici, who used, instead of water, spirits of wine (alcohol), and, having heated the spirits until all the air was expelled from the stem, sealed the end of the stem, thus arriving at the modern form of the thermometer. An attempt was also made at the same time to fix the graduations, or markings, on the thermometer according to some definite rule. It was first of all suggested that the

cold of winter and the heat of summer should determine two points on the thermometer, and then that the space between those two points should be divided into forty (or eighty) steps or degrees. This did not prove satisfactory, however, for some days in winter are colder than others, and a similar remark applies to summer days. Even the temperature of snow and ice varies, so that could not be taken.

The news of the new instrument soon spread to various countries, and it is said that Boyle introduced it into England. Some improvements were made, one of which was the substitution of mercury for alcohol. Mercury expands very uniformly, it is easily seen in a glass tube, and it does not boil till it reaches a very high temperature. For these and other reasons it is preferable to alcohol.

Fahrenheit.

It was not till the first decade of the eighteenth century that the next definite improvement came. Gabriel Fahrenheit, a native of Danzig, became interested in physics while he was receiving a business education at Amsterdam. He ultimately became a maker of meteorological instruments (that is, instruments used in studying the weather), and interested himself specially in the thermometer. After making many attempts to find a suitable scale to which there would be no serious objection, he arrived at one which is used to this day. Here is how he himself described it in 1724: "The scale of these thermometers, which are used only in meteorological observations, begins with 0 and ends with 96. This scale depends upon the determination of three fixed points which are obtained as follows. The first, the lowest, is found by a mixture of ice, water, and sal-ammoniac or sea-salt; if the thermometer is dipped in this mixture, then the liquid falls to the point marked 0. The second

point is obtained if water and ice are mixed without the salt; if the thermometer is dipped in this mixture it will stand at 32°. The third point is at the 96th degree, and the alcohol expands to that point if the thermometer be held in the mouth or arm-pit of a healthy person." At first he used only the first and third as his fixed points, and the interval was divided into twenty-four parts. The degrees, however, were too large, and each was divided into four parts; hence the number 96. He probably introduced the melting point of ice later as a check on the other two, after he had found out that ice always melts at the same temperature.

Now this was a vast improvement on previous scales, and we are told that there were at that time somewhere about fifteen scales in use. It had only one weak point, and that was that the temperature of the human body is not always exactly the same, though it does not vary as much as you might imagine. Fahrenheit stipulated a "healthy person"; there are, however, slight variations among different individuals, but they are so slight that for this purpose they could be neglected, save for very accurate work. Seeing that he took the melting point of ice as one of his fixed points, he might also have taken the boiling point of water as the other, for he knew that liquids have a fixed boiling point; but you must remember that the thermometer Fahrenheit used at first contained alcohol, and was used only in connection with the weather, so that temperatures higher than 96° were not encountered. Besides, if he had placed a thermometer in boiling water, the alcohol would have boiled, and burst the tube. It was not until he came to use mercury that he adopted the boiling point of water as his upper fixed point. How did it come to be 212°? That was surely a curious number to choose. Well, it was not chosen. That number was arrived at simply by continuing the scale above 96°; and

it just *happened* that the boiling point of water was 212°. Fahrenheit's thermometer was adopted in Germany and in Britain, and is used in these countries to this day.

Réaumur and Celsius.

Among the many suggestions as to thermometric scales was one by Réaumur of Rochelle. He suggested that the lower fixed point should be the melting point of ice, and should be called 0°, while the higher fixed point should be the boiling point of water, and should be called 80°. Why he chose the number 80 is not quite clear. This scale came to be used in France and Russia, but it was superseded shortly afterwards, in 1742, by another suggested by Celsius, who was Professor of Astronomy in Upsala. His fixed points were the same as Réaumur's, but he named one of them differently. The melting point of ice he called 0°, and the boiling point of water 100°; hence it came to be known as the centigrade scale, because there were a hundred steps or degrees between the fixed points. Besides being used in France and Russia, the centigrade thermometer is now preferred before all others for scientific purposes in every country.

Now that the necessary instrument was at last perfected, the science of heat was in a position to make its entry.

Our Senses Unreliable.

In a general way, we can tell by our sense of touch when one body is warmer than another; but our senses are by no means reliable authorities in this direction, as a very simple experiment will show. Take three basins; fill one with cold water, one with lukewarm water, and the third with hot water. Put one hand in the cold water, and the other in the hot water, and leave them there for two or three minutes. Then simultaneously plunge both hands into the lukewarm water. The hand that came from the

hot water will feel cold, while the hand that came from the cold water will feel warm ; and yet both hands must be at the same temperature. Our present sensations depend on immediately preceding ones. If you come in from a long walk, you will probably find it unbearably warm in a room where another person, who has not had any exercise, is crouching over a fire to keep warm.

These examples show that we cannot depend on our bodies to give correct indications of temperature ; so many other considerations enter that our feelings are not reliable. The thermometer, on the other hand, depending as it does only on the expansion of mercury due to heat, gives us trustworthy information as to temperature, and is indispensable in any investigations as to heat and its effects.

CHAPTER XVII

EXPANSION

(1) Solids

From the first few experiments you do on the subject of heat you learn that solids, liquids, and gases expand when heated and contract when cooled. We have seen that the expansion of liquids is made use of in the thermometer. You learn also that different solids and different liquids expand by different amounts for the same rise in temperature, but that different gases expand by the *same* amount for the same rise in temperature. When, however, you come to try to measure the actual expansion in each case, difficulties arise which, at first, seem to be unsurmountable. In the case of solids, the expansion is so very small that it is not visible to the unaided eye. In the case of liquids and gases, the containing vessel expands as well as the contents on being heated, and if this is not taken into account, the result obtained for the expansion is too low.

Measurement of Expansion.

The amount by which a metal rod increases in length when it is heated depends on three things: (1) the original length of the rod; (2) the rise in temperature; (3) the nature of the substance composing the rod. This last factor in the expansion, which depends on the nature of the substance, is a fraction called the coefficient of linear expansion It is defined as the ratio of the increase in

length produced by a rise in temperature of 1° C. to the original length ; or, as numerically equal to the expansion of unit length for a rise in temperature of 1° C. The coefficient of expansion of solids is a very small fraction, because, even for a very large increase of temperature, a solid expands only a very small amount. Because of this fact, it is a rather difficult matter to measure the expansion accurately without using some device for magnifying it. All the methods of finding the coefficient of expansion of a solid employ some such device. The magnified expansion is measured, and the magnifying power of the instrument is known, or can readily be found, and hence the actual expansion may be calculated.

Illustrations of Expansion.

The expansion of solids due to heat is a fact that must be taken into account in industry. In making railways, especially if the rails are laid in cold weather, a space is left between each rail to allow for expansion in summer. In all metal structures, a similar allowance has to be made, and it is sometimes a serious problem how to obtain a strong, reliable structure, and, at the same time, leave room for its various parts to expand. When this fact of expansion is kept in mind, it makes engineering feats such as the Forth Bridge all the more marvellous ; on the 1700-feet span of this huge bridge a space of about 18 inches has to be left to allow for expansion. An observant person might notice that the sag of telegraph wires is greater in summer than in winter, because the heat of summer makes the wires longer. Wires have been known to break in winter owing to the contraction caused by the low temperature. Thick glass vessels crack when hot water is poured into them, because the inside expands before the heat has time to get to the outside, and the irregular expansion causes the crack. Beakers used in a

laboratory are invariably made of thin glass. The glass stopper of a bottle that is not used very often sometimes becomes so firmly fixed into the neck of the bottle that it cannot be removed without the risk of breakage. When this happens, the best way of loosening it is to heat the neck gently, which causes it to expand, and then the stopper comes out quite easily.

Standard of Length.

In Chapter II. the standards of length were described. You will now realise that, for great accuracy, account must be taken of the variation in length of the standard due to differences in temperature. Thus the metre is defined as the distance between two marks on a platinum bar, the bar being at the temperature of melting ice, that is, 0° C. Even though the difference between its length at 0° C. and its length at the ordinary temperature, say 14° C., is very small, still, for very accurate work, it must be allowed for. Similar remarks apply to the standard yard ; in this case it is correct, by definition, at 62° F.

Force exerted during Expansion and Contraction.

Although the expansion of a metal bar is small, it exerts a considerable force against anything that tends to prevent its expansion. If the bars of a furnace were firmly fixed at both ends, their expansion when they were heated by the furnace would either loosen the masonry in which the bars were embedded, or the bars themselves would bend. Hence they are generally fixed only at one end, or else not fixed at all, being allowed to rest on cross-bars.

This force, however, is sometimes usefully employed. In the making of cartwheels, after the wooden framework has been constructed, the iron rim, which has been made slightly smaller in diameter than the wheel, is heated until it can just slip on to the wheel. Then, by pouring cold

water over it, it is cooled, and, in contracting, not only does it fit tightly on to the wheel, but it also binds the parts of the wheel firmly together.

Grid-iron Pendulum.

The time taken by a pendulum to swing backwards and forwards depends on its length, and its length is affected by heat and cold ; therefore, unless some arrangement is made to counterbalance these changes, the rate at which a clock, controlled by a pendulum, goes will vary according to the temperature. Several methods have been suggested to get over this difficulty, one of which turns to account the fact that different metals have different coefficients of expansion. For example, the coefficient of expansion of brass is about one and a half times that of steel. Hence, for the same rise in temperature, a rod of brass would expand by the same amount as a rod of steel one and a half times as long. If two such rods were fixed together at one end, and their temperature raised equally, then the distance between the free ends would always be the same. This is the principle underlying the grid-iron pendulum, as it is called, which was devised by John Harrison, a man of humble origin but of great inventive genius, who devoted a lifetime to the construction of clocks and watches. The pendulum consists of a series of rods alternately of steel (thin lines in Fig. 53) and of brass (thick lines). They are fitted together in such a manner that, with a rise in temperature, all the steel rods expand downwards while all the brass rods expand upwards

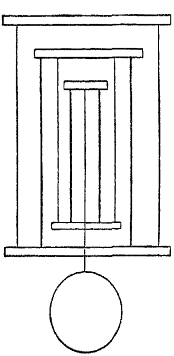


FIG. 53.

The lengths of the rods are so arranged that the total expansion of the steel rods downwards exactly equals the total expansion of the brass rods upwards, so that the bob of the pendulum is neither raised nor lowered, and the time of its swing is made independent of temperature.

(2) LIQUIDS

It must be remembered when dealing with liquids that, to obtain the real expansion, we must take into account the expansion of the containing vessel. For most purposes, however, it is sufficient to know the coefficient of apparent expansion.

Coefficient of Apparent Expansion of a Liquid.

The following is a simple and easily understood method of finding the apparent expansion of a liquid. A 4-ounce conical flask is filled to the brim with the liquid and the temperature taken. A one-holed rubber stopper through which passes the pointed end of a pipette is put into the neck of the flask, and the height to which the liquid rises marked by means of a strip of gummed paper or a thin rubber band. The flask is now immersed in a basin of hot water (about 60° C.) and allowed to remain until the liquid stops expanding. The new level is marked as before and the temperature taken. The flask is now emptied and filled with water up to the first mark and the volume found using a measuring jar. Water is now sucked up into the pipette till it stands at the top mark and the water run into a burette containing water till the level falls to the lower mark; this gives the number of cubic centimetres which the liquid expanded. The original volume and the rise in temperature being known, the coefficient of apparent expansion may then be calculated.

Peculiar Behaviour of Water.

While it is a general rule that liquids expand when heated and contract when cooled, there is a very important exception, which we must now consider. If a flask completely filled with water is fitted with a cork through which passes a long glass tube so that the water stands well up in the tube (at A in Fig. 54), and the flask is surrounded by a freezing mixture, the water will, of course, contract, and the level in the tube will fall. After a short time, however, the level of the water stops falling (at B), and actually *begins to rise*, stopping at C, when the water begins to freeze. This shows that the water stopped contracting at a certain point, and began to expand. If the flask is then taken out of the freezing mixture, and allowed to come back to the temperature of the room, the level first of all is lowered, and then begins to rise. It appears then, that, when water is cooled, it contracts until it reaches a certain temperature, and that further cooling causes expansion.

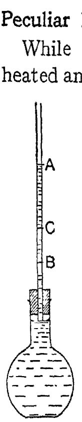


FIG. 54.

Hope's Experiment.

In order to find this temperature, Hope devised the following experiment. A tall glass jar is filled with water, and a freezing mixture is applied to the middle of the jar (as shown in section in Fig. 55). Thermometers are inserted through holes in the side of the jar at the top and the bottom. The freezing mixture cools the water in the middle, and the first visible effect is a decrease in temperature shown by the lower

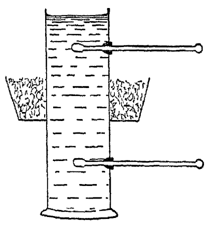


FIG. 55.

thermometer ; the upper thermometer is hardly affected. The water in the middle has contracted, and, becoming denser, has fallen to the bottom, causing a lowering of the temperature there. The lower thermometer continues thus to fall, but *it stops at* 4° *C*. Now the upper thermometer begins to fall, and it falls right down to 0° C. This shows that below 4° C. the water, on cooling, expands, becoming less dense, and therefore rising to the surface. The density of water is therefore greatest at 4° C.

Standard of Weight.

When the Metric System was introduced at the time of the French Revolution, it was decided that the standard of weight was to be the weight of 1 cubic centimetre of water. You will see now that some condition had to be made as to the temperature of the water, for the weight of 1 cubic centimetre is different at different temperatures. It was decided that the weight should be taken at the temperature where the density was greatest, namely, 4° C.

Freezing of a Pond.

This peculiar behaviour of water is of great importance in nature. On a cold day in winter, the water on the surface of a pond is cooled, contracts, and sinks to the bottom, warmer and less dense water rising to take its place. If this process went on right down to freezing point, then all the water in the pond would freeze at about the same time from the bottom upwards. But this does not happen, because, as soon as the temperature reaches 4° C., the circulation stops ; below that temperature the water expands on cooling, and remains on the surface, so that ice forms on the surface first, the layer gradually increasing in thickness. The water at the bottom may never fall below 4° C., and thus fish are able to live in ponds through even a severe winter.

(3) Gases

Boyle's Law—a Condition.

Gases differ from solids and liquids in many respects. A solid has a definite volume and a definite shape; a liquid has a definite volume but no definite shape; a gas has neither definite volume nor definite shape—it takes the volume and shape of the vessel that contains it. The application of pressure to a solid or to a liquid causes practically no change of volume, but as the pressure on a gas is increased its volume is decreased at the same rate, as Boyle discovered. Now we see that the volume of a gas depends, not only on its pressure, but also on its temperature, for heat causes it to expand, that is, causes its volume to increase. The expansion, too, is much greater than in the case of solids and liquids. Thus in stating Boyle's law, it must be understood that there is no change in temperature, otherwise the statement would not be true. It should read: the volume of a gas is inversely proportional to the pressure, provided the temperature is unchanged. Similarly, in dealing with the change in volume of a gas due to heat, we must stipulate that the pressure be kept constant. When this condition is complied with, it is found that all gases expand by an equal amount for the same rise in temperature.

Charles's Law.

During the first half of the nineteenth century, the expansion of gases was investigated by various scientists. Professor Charles discovered the fact of the equal expansion of gases, and measured the expansion. He embodied his discoveries in a statement now called Charles's law, which is, that the volume of a gas, kept at constant pressure, increases by a definite fraction of its volume at 0° C. for each degree rise in temperature. It must be noted that it

is the fraction of its volume *at* 0° *C.* that is taken, because, in the case of a gas, the volume changes so much that the fraction would be very different if another temperature were taken. For this reason 0° C. has been chosen as the standard or normal temperature. The fraction is, of course, the coefficient of expansion of the gas ; its value for every gas is 0·00366 or $\frac{1}{273}$. Thus, if the volume of a gas at 0° C. is 1 cubic centimetre, its volume on being heated would become

at 1° C. $(1+\frac{1}{273})$ c.c.
at 2° C. $(1+\frac{2}{273})$ „
at 35° C. $(1+\frac{35}{273})$ „
at 273° C. $(1+\frac{273}{273})$ „

Its volume would therefore be doubled at 273° C. Charles's law holds good, not only for expansion on heating, but also for contraction on cooling. Thus, on being cooled, 1 cubic centimetre at 0° C. would become

at −1° C. $(1-\frac{1}{273})$ c.c.
at −2° C. $(1-\frac{2}{273})$ „
at −35° C. $(1-\frac{35}{273})$ „
at −273° C. $(1-\frac{273}{273})$ „

Absolute Zero.

According to this last statement, the volume of a gas would be reduced to 0 at − 273° C. Because of this result, the temperature − 273° C. is called the Absolute Zero of temperature, and a scale of temperatures with this zero is called the Absolute Scale. It is easily seen that the Absolute Temperature corresponding to any given centigrade temperature is found simply by adding 273° to it. It should be noted that, although theoretically the volume of a gas is reduced to 0 at − 273° C., actually this is not the case. This is a good example of how one may be led to erroneous conclusions by working theoretically instead

of experimentally. In this case, no gas exists at such a low temperature as $-273°$ C.; they are all converted into liquids before they reach $-273°$ C., and since they are no longer gases, Charles's law does not apply to them.

The Gas Laws.

If a gas occupies 10 cubic centimetres at 0° C., then its volume at 20° C. will be $10(1+\frac{20}{273})$ or $10(\frac{273+20}{273})$ cubic centimetres. At 30° C. its volume will be $10(1+\frac{30}{273})$ or $10(\frac{273+30}{273})$ cubic centimetres. The numerators of these two fractions represent the absolute temperature of the gas in each case, and, since otherwise the expressions are the same, we can say that the volume is directly proportional to the absolute temperature. We can combine Boyle's law and Charles's law in a single statement thus: The volume of a gas is inversely proportional to the pressure and directly proportional to the absolute temperature.

N. (or S.) T.P.

The measurement of the volumes of gases is a very frequent operation in physics and chemistry, and it is important, in view of your future work, that you should understand those two laws thoroughly. For purposes of comparison of results of experiments made under different conditions of temperature and pressure, it is usual to calculate, using the two gas laws, the volume a gas would occupy at 0° C. and 76 centimetres pressure. The volume is said to be reduced to normal (or standard) temperature and pressure, or, more shortly, to N. (or S.) T.P.

CHAPTER XVIII

TRANSMISSION OF HEAT

(1) Conduction

Conduction Explained.

If you push the point of a poker into the fire, leave it there for some time, and then take it out again, you will find that the handle is now hot—perhaps too hot to hold. The heating has not been confined to the point of the poker in the fire. How did the heat reach the handle? Most of it was "conducted" along the poker itself. You will be shown experiments which prove that the heat travels along the poker gradually; it is, as it were, handed on from particle to particle until it reaches the end. This method of transmitting heat is called conduction.

Good and Bad Conductors.

Solids differ very much in their power of conducting heat. As a rule, metals are good conductors, silver and copper being the best. Substances like glass, wool, paper, and wood are bad conductors, that is, heat is not easily transmitted through them. If you hold a piece of paper in a flame, it will burn; yet it is possible to hold a piece of thin paper for some time in a flame without even scorching it, if it is wrapped tightly round a piece of metal. The metal carries away the heat so quickly that the temperature of the paper does not rise high enough to cause it to burn, until, of course, the metal itself becomes hot.

Illustrations.

In everyday life, we make extensive use of some bad conductors of heat. For example, in winter we wear

woollen underclothing, woollen scarves, and furs, because those materials, being bad conductors of heat, do not allow the heat of the body to pass through them, or, at least, do so only very slowly. Again, very often the handles of kettles and teapots are made of wood or of vulcanite, which do not allow heat from the hot water or the tea to pass through them as much as a metal handle would do. They can thus be used with greater comfort. It is sometimes overlooked that while bad conductors keep *in* heat, they also keep *out* heat. If some ice has to be kept in warm weather and no ice-chest is available, then by wrapping it in flannel the heat of the air will be kept away from it.

If you go round an unheated room on a cold winter day, and touch various objects in the room, you experience different sensations. Fire-irons and metal knobs feel very cold, furniture not so cold, and carpets and rugs probably cause little or no sensation. Since all these articles are in the same room, and it is not heated, they are all at the same temperature, or the difference, if any, is very small. How does it come about that they feel different? The explanation is contained in their different conductivities. When you touch the metal knob, heat from your hand is conducted away quickly, and it is when heat is leaving your body that you feel cold. When, however, you touch the carpet, which is a bad conductor, heat is not carried away so quickly, and hence you do not feel it cold. It must be remembered that cold is simply absence of heat; it is not something entirely different.

Ignition Point.

A substance that is inflammable will not burn unless it is raised to a certain temperature, usually called its ignition temperature. For example, you know that sometimes there is a little difficulty in lighting a coal fire, because the coal must be raised to a certain temperature by means of

paper and sticks before it will begin to burn. In the experiment referred to above when paper was wrapped round a piece of metal and held in a flame, the heat was conducted away so quickly that the ignition temperature of the paper was not reached. A piece of wire gauze when it is lowered on a gas flame does not allow the flame to pass through, for it conducts away the heat, and the gas passes through it unburnt. The gas can be ignited on one side of the gauze, and the flame does not pass through, unless the gauze becomes red-hot.

Davy Lamp.

Upon this fact the miner's safety-lamp depends. Sir Humphry Davy was a renowned scientist who lived at the

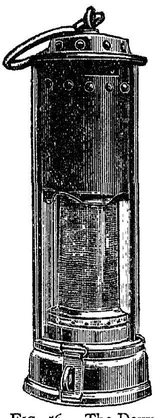


FIG. 56.—The Davy Lamp.

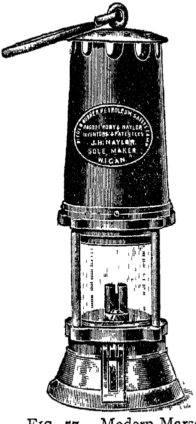


FIG. 57.—Modern Marsaut Miner's Lamp.
(*By courtesy of Messrs. J. H. Naylor Ltd.*)

beginning of the nineteenth century. He early took to the study of science, and overcame the obstacles that lack of

money put in his way by the simple means of making the most of what was available. His apparatus at first consisted of such household articles as teacups, wine-glasses, and tobacco-pipes. He rose to fame by his investigation of the gas which is popularly called "laughing gas," a gas sometimes used by dentists to render patients unconscious during extraction of teeth. One of his minor achievements, though it is the one by which he is best known, and one which has contributed directly to human welfare, was his invention of what is now known as the Davy lamp. Up till Davy's time, accidents in coal mines due to explosions were very frequent. A gas, generally called fire-damp, accumulates in some mines, and is a source of great danger if naked lights are used. The Davy lamp is an ordinary oil-lamp, the flame being surrounded by wire gauze. Fire-damp in the atmosphere of a coal mine may pass through the gauze, but it burns quietly inside, since the gauze conducts away the heat so rapidly that the flame does not pass through to the outside. Nowadays, a miner can work in perfect safety even in a very "fiery" mine. Explosions still occur from time to time, but they are due either to carelessness or to a faulty lamp.

Conduction in Liquids and Gases.

Liquids, as a rule, are bad conductors of heat (mercury is the exception), as can be shown by a simple but convincing experiment. A test-tube full of water may be held by the bottom, and the upper part of it heated by a flame. Soon the water at the top will boil, and yet there will be no appreciable rise in temperature at the bottom.

Gases are even worse conductors of heat than liquids, and this fact is turned to good account in the storing of ice. Ice-chests are made with a double wall, leaving an air-space between. Since air is a bad conductor, heat from the outside does not easily pass through to the ice.

A similar arrangement holds good in the hay-box, which was popularised during the Great War as an economiser of fuel. It consists of a double box, the space between being packed with hay or some other non-conducting material, or is simply left full of air. The article to be cooked is heated for some time in the usual way, then it is put into the hay-box, where, the heat not being allowed to escape, it continues to cook. Another name sometimes given to this useful contrivance is the Norwegian Stove.

The Thermos Flask.

The same idea exists in the Thermos Flask. It consists of two flasks, one within the other, the space between in this case being a vacuum, which is even more effective in preventing the conduction of the heat than if the space contained air. Hot tea or coffee carried in the flask keeps its heat for many hours, the only loss being due to conduction along the material composing the flask (see Fig. 58).

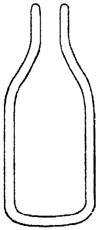


FIG. 58.

Materials like fur, eider-down, and wool owe their non-conducting power very largely to the air that is entangled in them.

(2) CONVECTION

Convection Explained.

Referring again to the above experiment in which water was heated in a test-tube held by the bottom, you might remark that that is not the usual way of heating water. It is, of course, most convenient to heat a vessel at the bottom. Let us see what happens when a vessel full of water is heated in this way. When the heat is applied, that part of the vessel in contact with the flame

is heated first, and the heat is conducted through the material to the water at the bottom. This causes that part of the water to expand, and, being thus rendered less dense, it ascends, while colder, and therefore denser, parts of the water descend. These, in turn, are heated and ascend, and so a circulation is set up in the water. Thus, in a vessel full of liquid that is being heated, there is a constant upward current that carries heat with it. This method of transmitting heat is called convection, because the heat is " carried " by particles of the substance. In conduction, the heat is handed on from particle to particle, but the particles themselves do not move ; in convection, the heat is distributed by the movement of the particles. It is obvious that convection currents can be produced only in liquids and gases.

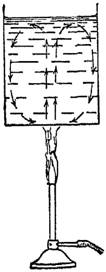


FIG. 59.

Probably the most familiar example of convection in gases is the draught up a chimney. The air is heated by the fire; it expands, and so becomes less dense. It rises up the chimney, its place being taken by colder air from the room, which, in turn, is heated, and is carried upwards.

In the laboratory, you have prodably noticed, though you may not have had occasion to use, several draught cupboards or fume chambers. When poisonous or evil-smelling gases are being dealt with, the work is done in those cupboards to avoid the contamination of the atmosphere. In order to take away the fumes, a gas jet is lit, which sets up a convection current in the flue.

Ventilation.

All systems of ventilation are merely methods of setting up convection currents between the air in a room and the

outside air without creating draughts in the room. The air in a room is heated by the fire, or by a gas jet, or by our own bodies. This hot (and impure) air rises to the top of the room, and, if it has no adequate means of escape, all the air in the room soon becomes hot and impure, and therefore unhealthy. Hence rooms must be well ventilated if we are to have pure air for respiration. Two things are necessary for the proper ventilation of a room—an outlet for the warm and impure air near the top of the room, and an inlet for cold pure air near the bottom.

(3) Radiation

Radiation Explained.

If the point of a poker is pushed into the fire, and left for some time, the handle, as we have seen, is heated by conduction. If it is withdrawn when the point is red-hot, and you put your hand above it, you feel the sensation of heat which is mainly due to a current of heated air rising from the poker, that is, to a convection current. If now you put your hand *below* the red-hot poker, you still feel the sensation of heat. Since gases are bad conductors of heat, this effect cannot be due to conduction Since heated air ascends, it cannot be due to convection. It is due to the direct transmission of heat from the poker to your hand, which is called radiation. It is by this method that your hands are warmed when you hold them in front of the fire.

Radiation differs from the other two methods of transmitting heat in two respects. In the first place, radiation takes place in straight lines, and in all directions. By convection, heat is transmitted only upwards, and not necessarily in straight lines. In conduction, the direction is limited by the shape of the solid. The sun heats the earth by radiation. That radiant heat travels in straight lines is clearly shown by the fact that we seek relief from

the sun's hot rays by going into the shade. Similarly, if the fire is too hot, the radiant heat can be cut off by holding a book or a newspaper between the face and the fire. In this respect heat is like light, which also travels in straight lines, but unlike sound, which can travel in any direction; you can hear a noise round a corner, but you cannot see round a corner.

Secondly, when heat is radiated, the substance through which it passes is not heated to any appreciable extent. You may question this statement by remarking that the air is warm on a hot day, and that therefore the radiant heat from the sun heats the air as it passes through it. The sun, however, does not directly heat the air, as is shown by the fact that the higher you ascend the colder the air becomes. The sun heats the earth, and the air is heated from the earth by convection. On a still hot day, you can actually see convection currents set up in the air by the heat of the earth: it looks as if the air were quivering.

Leslie's Experiments.

Some of the phenomena of radiant heat were investigated by Sir John Leslie, who was a native of Largo, at the beginning of last century. In order to examine the radiating powers of different substances, he devised an instrument called the Differential Air-thermometer. This consists of a narrow tube bent as in Fig. 60, at each end of which there is a bulb. The tube contains a certain amount of liquid. If one of the bulbs is heated, the air in it expands and alters the levels of the liquid. By means

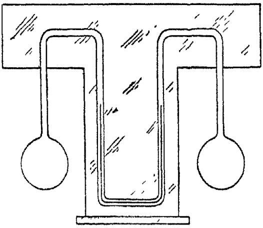


FIG. 60.

of this instrument, very small differences of temperature may be noticed. As its name implies, it does not measure temperature, but only indicates differences of temperature between the two bulbs.

Leslie used cubical vessels (still known as Leslie's cubes) filled with hot water, and coated on the four vertical sides with substances whose radiating powers he wished to determine. The heat radiated from each surface in turn was allowed to strike a bulb of the air-thermometer. In this way, he found that a surface covered with lampblack radiated eight times more heat than one covered with polished nickel, both being at the same temperature. These were the extremes, other substances being intermediate in radiating power. He found also that radiation depends, not only on the temperature of a body, but also on the nature of its surface. For instance, one of his experiments showed that tarnished lead radiated nearly three times as much as a bright lead surface.

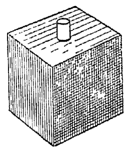


FIG. 61.

Good Radiators are Good Absorbers.

If two vessels full of water, the exterior of the one being polished and of the other blackened, are left for some time at the same distance from a source of heat, it is found that the water in the blackened vessel is at a higher temperature than that in the other. This shows that a blackened surface also absorbs heat more quickly than a polished surface, which reflects the heat as it does the light. If several substances are tested as to their absorbing power, and a list is drawn up, it is found, on comparing this list with one showing the radiating powers of the same substances, that the order is the same. Thus good radiators are also good absorbers of heat.

Those facts explain why, as a rule, kettles are black, while teapots are bright and polished. A black kettle absorbs heat more quickly than a polished one, and so requires less heat to boil water. A teapot, if its surface were black, would lose its heat very quickly, but the bright polished surface does not radiate heat quickly.

Heating by Hot Water Pipes.

The heating of large buildings by means of hot-water pipes illustrates the three methods of transmission of heat. A boiler is situated in the basement of the building, and the water in the boiler is heated by a furnace (conduction). The heated water rises to the top of the boiler, where there is a pipe which leads through the building. The hot water passes up through the pipe (convection). In each room to be heated, there is a coil of pipes, which are heated by the hot water passing through them (conduction). Each coil, in turn, radiates heat into the room (radiation); hence the name of such coils, "radiators." Only a small part of the heat in the hot water, however, is transmitted to the room by radiation; a great deal more is transmitted by convection, the air in contact with the pipes being heated, and rising. A better name for the coil of pipes would be "convector" instead of "radiator."

CHAPTER XIX

CHANGE OF STATE

(1) Fusion and Solidification

Melting Point of a Solid.

We have seen that the application of heat to a solid, as a rule, causes the solid to expand. In most cases, if the temperature is raised sufficiently, another change takes place: the solid is converted into a liquid. This change of state is called melting or fusion. Thus ice melts or fuses at 0° C., tin at 232° C., wrought iron at 2000° C. Some substances, such as carbon and lime, have not yet been fused. As a rule, the change from solid to liquid takes place at a definite temperature, called the melting point. The reverse process, solidification, takes place at the same temperature. Thus 0° C. is the melting point of ice and the freezing point of water. If the bulb of a thermometer is put among some wax, and the wax is heated very gently, it will be found that the temperature rises until a certain point is reached, when further heating does not cause a rise in temperature. If the wax is now examined, it will be seen that it has begun to melt, and the temperature will not rise further until all the wax has melted. Whenever that has taken place, the temperature will immediately begin to rise again. The temperature at which the thermometer remained stationary is the melting point of the wax.

Lowering of Freezing Point.

If a little common salt is mixed with some ice, and a thermometer placed in the mixture, it is found that the temperature falls below 0° C.; or if a solution of salt in water is cooled, it will not freeze until a temperature below 0° C. is reached, the actual temperature of solidification depending on the strength of the solution. Upon this fact depends the use of freezing mixtures used for the artificial production of ice. Confectioners use a mixture of equal weights of common salt and ice in the making of "ices." Salt is frequently sprinkled on pavements to clear off snow which has been tramped hard, but this practice is not altogether to be commended, for a freezing mixture is thus formed which makes the pavement so cold that, even if the snow is swept off, water freezes on it into a smooth sheet of ice.

Expansion of Water on Freezing.

It has already been remarked that ice is less dense than water, since it floats on water (Chap. VI.). This indicates that water, when it freezes, expands, thus continuing the process begun at 4° C. In this respect, water is again an exception to the general rule, for most liquids on solidification contract. Not only does water expand on freezing, but it exerts considerable force in doing so. The most familiar example of this is the bursting of water-pipes during frost. When the water in a pipe freezes, it expands, and the ice therefore requires more room than did the water. If the pipe does not yield, it is broken, or if it is made to yield too much it is burst by the force of the expansion. The result is that when the thaw sets in, it is found that the pipe is leaking, and the services of a plumber are required. You may have noticed that water-pipes which are exposed to the air are frequently wrapped round with straw or sacking. The reason for this will be

obvious when you remember that such materials are bad conductors of heat; they prevent the water in the pipes cooling to freezing point.

The expansion of water on freezing is a powerful agency in the breaking up of rocks. Rain enters into all the little crevices in the rocks, and, when frost comes, those little drops of water freeze and expand, the force of expansion being sufficient to cause pieces of the rock to be broken off.

Measurement of Heat.

Up till now, nothing has been said about the measurement of heat. The thermometer, it must be remembered, does not measure heat, but only temperature, or hotness. If 100 grams of water are heated from 10° C. to 20° C., a certain definite amount of heat is given to the water, and the same amount will be given out by the water if it is cooled from 20° C. to 10° C. To raise the temperature of 200 grams of water at 10° C. to 20° C., twice as much heat will be required; to raise that of 300 grams, three times as much, and so on. Just as we require units for the measurement of volume, weight, etc., so a unit is necessary for the measurement of heat. The unit chosen is the amount of heat required to raise the temperature of 1 gram of water 1° C., and is called the calorie. The amount of heat necessary to raise the temperature of 1 gram of water 10° C. is 10 calories, and the same amount will also raise the temperatere of 10 grams of water 1° C.

Latent Heat of Water.

About the middle of the eighteenth century, Joseph Black, who was then Lecturer in Chemistry in Glasgow University, completed important researches in heat. Black noticed that, when ice at 0° C. is heated, the temperature indicated by a thermometer does not rise till all the ice has melted. What, asked Black, becomes of all the heat

that is given to the ice ? His reply was that, in some way, the heat was used up in converting the ice into water. The thermometer gave no indication that the ice was receiving heat, and Black therefore thought of it as hidden in the water, and he called it latent heat. The latent heat of water (or fusion of ice) is the amount of heat required to convert 1 gram of ice at 0° C. into 1 gram of water at the same temperature. By experiment, it is found that 80 calories are required to make this change, and, of course, 80 calories are given out when 1 gram of water at 0° C. is changed into 1 gram of ice at the same temperature. Water therefore must lose a large amount of heat before it is changed into ice. This explains why, in winter, the thermometer may stand at 0° C., and yet there may be no ice on the surface of a pond. The water must lose by radiation its latent heat before it will freeze. On the other hand, the fact of latent heat gives the reason for the persistence of snow and slush after a snowstorm. To melt the snow, each gram must receive 80 calories, that is, the same amount of heat as would raise the temperature of 1 gram of water 80° C.

The reality of latent heat may be shown in rather a striking manner by the following experiment. If 100 grams of water at 80° C. are mixed with 100 grams of water at 0° C., the final temperature of the 200 grams will be 40° C. ; but if 100 grams of water at 80° C. are mixed with 100 grams of *ice* at 0° C., the final temperature will be 0° C. All the heat given out by the hot water in cooling from 80° C. to 0° C. is required to convert the ice at 0° C. to water without raising its temperature.

(2) Vaporisation and Condensation

Boiling Point of a Liquid.

If you heat some ordinarv tap water in a glass vessel,

before long small bubbles are seen in the water, which rise to the surface and disappear. It can easily be proved that those bubbles consist of air which was dissolved in the water, and which was expelled by the heat. As the heating is continued, larger bubbles make their appearance ; these are caused by the water nearest the source of heat being converted into steam. These bubbles of steam ascend, and, coming in contact with colder water, the steam partly condenses, and when what is left of each reaches the surface, it collapses with a slight noise. It is this noise that causes the " singing " of a kettle, which is regarded as a sign that the water is nearly boiling. When boiling does take place, steam is formed and rises as before, but since all the water is at the same temperature, the steam does not condense but escapes into the air. It should be noted here that steam is invisible ; the cloud that is seen issuing from a kettle of boiling water really consists of small particles of water. The steam, coming in contact with the air, which is at a lower temperature, condenses. Perhaps you have noticed that there is a space between the spout and the cloud ; that space is filled with steam, and the cloud is that steam condensed.

Evaporation.

While water may be changed into steam by boiling it, the change may be effected without boiling. After a heavy shower of rain in summer, water lies in pools in the streets, but a wind or a strong sun will soon dry the streets again. The water has been changed into steam or vapour by evaporation. Evaporation is a slow process, and it takes place at any temperature, but only from the surface of the liquid ; boiling, on the other hand, is a rapid process, and it takes place only at a definite temperature and from those parts of the liquid nearest the source of heat.

Effect of Pressure on Boiling Point.

Each liquid when heated in an open vessel has a definite temperature at which it boils; for example, water boils at 100° C., ether at 35° C., mercury at 357° C. This fact was discovered by Fahrenheit in the course of his experiments on the thermometer, and he also noticed that the boiling point of liquid was not exactly the same every day, though the difference is sometimes very small. Further experiments showed him that the boiling point of liquids is affected by a change of atmospheric pressure, the boiling point being lowered by a decrease of pressure, and *vice versa*. On the top of a mountain the pressure is less than it is at sea-level, hence there the boiling point of water is less than 100° C. For example, in Quito, which is the highest city in the world (9520 feet), the normal height of the barometer is only 52·5 centimetres, and water boils at 90° C. Boiling water in Quito therefore is not so hot as boiling water in places at or near sea-level. Water in the boiler of a steam-engine at a pressure of 150 lb. per square inch boils at a temperature of about 181° C.

Effect of Impurities on Boiling Point.

Another factor that affects the boiling point of a liquid is the presence of substances dissolved in it. For instance, the boiling point of sea-water, in which salt and other substances are dissolved, is about 104° C., while that of pure water is 100° C. The number of degrees by which the boiling point is raised depends on the weight of the dissolved substance, that is, on the strength of the solution. The purity of a liquid can thus be tested by finding its boiling point.

Latent Heat of Steam.

When an open vessel of cold water is heated, its temperature rises until 100° C. is reached, at which point the water

begins to boil, and further heating does not raise its temperature. Heat is still passing into the water, and it follows that it must become "latent" in this case as well as when ice is heated and changed into water. When the boiling point is reached, further heating causes the change of state from water to steam. Similarly, when steam condenses to water, the latent heat is given out. The latent heat of steam (or vaporisation of water) is the amount of heat required to convert 1 gram of water at 100° C. into 1 gram of steam at the same temperature. Its value is found by experiment to be 536 calories. It therefore requires between six and seven times as much heat to change 1 gram of water at 100° C. into 1 gram of steam at 100° C. as to change 1 gram of ice at 0° C. into 1 gram of water at 0° C. The high value of the latent heat of steam explains why burns from steam are so severe; they are much more painful than burns from boiling water because of the heat given out by the steam in condensing.

Carré's Ice Machine.

Not only during boiling is heat absorbed to change the water into steam, but also during evaporation, the slower process, heat is necessary. This can easily be felt in the case of a liquid with a low boiling point. Such a liquid is ether. If you put a few drops of this liquid on the palm of your hand, the ether will evaporate very quickly, and, in doing so, extract heat from your hand, producing an intense sensation of cold. Water may be made to freeze by its own rapid evaporation, and a machine is constructed which makes use of this fact for the artificial production of ice. The machine, which was invented by Carré, is really an air-pump. A bottle of water is connected to the pump, and an arrangement made whereby the water vapour is absorbed. After working the pump for a few

minutes, the pressure is lowered to such an extent that the water boils. The heat necessary to convert the water into vapour is taken from the water itself, and thus the temperature is lowered. As the process is continued, the temperature gradually falls until it reaches 0° C., when the water is changed into ice.

In summer, water-carts are sent through the streets to lay the dust. Besides removing this source of annoyance, the water produces a cooling effect which is largely due to its evaporation. Why does a dog hang out its tongue when it is hot? Simply to expose a large surface for evaporation, so that it may benefit from the cooling effect. In hot countries, the problem of keeping water cool is a serious one, but it is accomplished by making use of this same cooling effect produced by rapid evaporation. The water is put into earthenware vessels which are porous, allowing the water to ooze out very slowly. The vessels are placed in a draught so as to cause the evaporation of this water that comes through the pores, and thus evaporation keeps the water inside cool. Similarly, in order to keep wine cool, bottles are wrapped in wet cloths, and set in a draught.

CHAPTER XX

SPECIFIC HEAT

Capacity for Heat.

If 100 grams of water at 10° C. are mixed with 100 grams of water at 30° C., the resulting temperature of the mixture will be 20° C. Heat passes from the water at the higher temperature to the water at the lower temperature until the temperature of the whole mass is the same; the temperature of the former falls 10° C., while that of the latter rises 10° C. It is assumed, of course, that no heat is lost by conduction or radiation.

If now 100 grams of water at 80° C. are mixed with 100 grams of turpentine at 20° C., the resulting temperature will be, not 50° C. as might be expected, but about 62° C. Thus the heat lost by the water in cooling through 18° C., namely 1800 calories, suffices to raise the temperature of the turpentine through 42° C. If mercury were used instead of turpentine under the same conditions, the result would be even more striking: the temperature of the mixture in this case would be 78° C. The water in cooling from 80° C. to 78° C. would lose 200 calories, and this amount of heat raises the temperature of the mercury from 20° C. to 78° C. From such experiments, it is seen that the same amount of heat given to different substances may produce different temperatures; or, to put it in another way, to produce the same increase in temperature in

different substances, different quantities of heat are required. This is expressed by saying that every substance has a different capacity for heat, or a different *specific heat.* This term is defined as the number of calories required to raise the temperature of 1 gram of a substance 1° C.

Method of Mixtures.

The discovery that different substances have different specific heats was made by Joseph Black, whose work on latent heat was mentioned in the previous chapter. All Black's work on heat followed very soon after the perfection of the thermometer by Fahrenheit. One of the methods of finding the specific heat of a substance was illustrated above, namely, the Method of Mixtures. When 100 grams of water at 80° C. are mixed with 100 grams of turpentine at 20° C., the resulting temperature is 62° C. The heat given out by the 100 grams of water in falling through 18° C. is 1800 calories. This amount of heat raised the temperature of 100 grams of turpentine through 42° C. Hence $\frac{1800}{42}$ calories would raise the temperature of 100 grams of turpentine 1° C, and $\frac{1800}{42 \times 100}$ would raise the temperature of 1 gram of turpentine 1° C.; therefore the specific heat of turpentine is $\frac{1800}{42 \times 100}$ or 0·43.

Black's Ice Calorimeter.

Black, however, devised a method for finding specific heats which, for simplicity and directness, has never been surpassed. He procured a large block of ice (Fig. 62), and, having ground one side of the block perfectly level, he formed a cavity in it. A lid of ice fitted tightly on the top of the block, so that the heat from the outside would not enter the cavity. The body whose specific heat was to be measured was raised to an accurately determined temperature, and, as quickly as possible, transferred to the cavity, which had previously been dried with an ice-cold cloth.

It was left there for several hours, and, of course, it caused some of the ice to melt. At the end of the time, the cavity contained water at 0° C. and the body at 0° C. The water thus formed was weighed, and, since the latent heat of the water was known, the number of calories required to convert this weight of ice into water could be calculated, and it was then an easy matter to determine the specific heat of the body.

An example will make the calculation clearer. A copper ball weighing 600 grams was heated to 100° C., and then

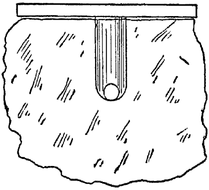


FIG. 62.

introduced into an ice-calorimeter, as it is called. The water produced was found to weigh 72 grams. Thus 72 grams of ice at 0° C. was changed into 72 grams of water at 0° C., and the heat necessary to make this change is 72×80 or 5760 calories. Now this quantity of heat must have come from the copper ball in cooling from 100° C. to 0° C. It follows that the amount of heat given out by the copper ball in cooling through 1° C. would be 57·6 calories, and that the amount of heat given out by 1 gram of copper in cooling through 1° C. would be $\frac{57 \cdot 6}{600}$ calories. Hence the specific heat of copper is $\frac{57 \cdot 6}{600}$ or 0·096.

Specific Heat of Mercury and Water.

The specific heat of mercury is very low (0·033), which fact is an additional recommendation for the use of mercury

in thermometers. When a thermometer is placed in a liquid, the bulb absorbs a certain amount of heat, and so lowers the temperature of the liquid slightly, but with a mercury thermometer the amount of heat absorbed is very small—much smaller than would be the case with an alcohol thermometer (the specific heat of alcohol is 0·55). Another advantage, which has not been mentioned before, is the high boiling point of mercury (357° C.) and its low freezing point (– 39° C.).

Water has a higher specific heat than any other liquid or any solid. Thus water, when it cools, gives out a large amount of heat, and cools very slowly. For this and other reasons, water is preferred for use in hot-water bottles, and for heating buildings.

Insular and Continental Climates.

Again, because of the high specific heat of water, the sea heats more slowly than the land under the influence of the sun's rays. On a hot day, the temperature of the sea will be less than the temperature of the coast. After sunset, the reverse will be the case, for the sea also cools more slowly than the land. It is for this reason that islands have a more equable climate than large continents at the same latitude; in fact, the two types of climate are called respectively insular and continental. The effect of the sea is to prevent the occurrence of extremes of heat and cold.

The local effect of the difference in the specific heats of sea and land is the setting up of land- and sea-breezes. Since the sea is cooler during the day than the land, the air above the sea is cooler than the air above the land. Hence, as the air above the land ascends, colder air from the sea flows in to take its place, producing a sea-breeze. After sunset, both land and sea begin to radiate heat, but as the land gives up its heat more quickly the air

over it cools faster than the air over the sea, and a breeze blowing from the land to the sea springs up which lasts all night ; this is a land-breeze. Those land- and sea-breezes do not occur regularly ; they may be overcome by larger and stronger winds arising from other causes.

REVISION QUESTIONS

VOLUME

1. Is there any difference between a cubic centimetre and a centimetre cube ?
2. What is meant by the volume of a body ?
3. What is a litre ?
4. What is the unit of volume (1) in the Metric System, (2) in the British System ?
5. How would you find the volume of a brick ?
6. How would you find the volume of a small, irregular stone ?
7. If you were given some water in a beaker and asked to find its volume, what instrument would you use ? Why ?
8. If you were asked to return a definite volume (say 20 c.c.) of the water in the beaker (Question 7), how would you proceed ?
9. How would you find approximately the capacity of a large flask ?
10. How would you find exactly the capacity of a small bottle ?
11. If you were given a number of pellets all the same size how would you find the volume of one of them ?
12. Describe a method of finding the volume of a cork.

DENSITY

13. What is meant by the statement that the density of copper is 8·9 grams per c.c. ?
14. Describe any method of finding the density of a small piece of brass of irregular shape.
15. How can the density of a liquid be found ?

16. Which do you think is the heavier—1 c.c. of sea-water or 1 c.c. of fresh water? How could you find out?
17. A sculptor wishes to know the weight of a rectangular block of marble which he has just shaped out. It is too heavy to weigh; how can he find its weight?
18. How would you find out whether a penny is made of pure copper?
19. If you were given a piece of metal and told it was pure, how could you find out which metal it was?
20. Three vessels each contain a colourless and odourless liquid. How could you find out with a fair degree of certainty whether the vessels contain the same liquid or different liquids?
21. An iron ball is suspected to be hollow. What would you do to find out whether it is or not?

FLOATING BODIES

22. Describe any method of finding the density of a small piece of wood.
23. How could you find the weight of a cork without actually weighing it?
24. How could you find the density of a wooden rod without using a balance?
25. If you were given a rectangular block of an unknown substance, how would you proceed to find out whether it would float or sink in water without wetting it?
26. What fraction of an iceberg is below the surface of the sea?
27. A solid lump of steel will sink in water. How is it that a ship which is largely made of steel floats?
28. If a ship is loaded with a cargo at Glasgow and then steams down the river Clyde into the Firth, it rises out of the water slightly. Explain this.
29. Will a lead pencil sink farther in water or in methylated spirits? Give a reason for your answer.
30. Describe the common hydrometer and state how it is used.
31. Why is it that a cup placed upright in water floats while a plate generally sinks?

SPECIFIC GRAVITY

32. What is meant by the statement that the specific gravity of mercury is 13·6 ?
33. If you are asked to find the specific gravity of anything what two quantities must you determine ?
34. Describe any method of finding the specific gravity of an irregular solid.
35. Describe any method of finding the specific gravity of a liquid.
36. Is the specific gravity of a substance the same in Metric units as in British units ? Why ?
37. How would you find the specific gravity of a powder ?

ARCHIMEDES' PRINCIPLE

38. State Archimedes' Principle.
39. How could you show the truth of Archimedes' Principle experimentally ?
40. How could you find the apparent weight of a body in water without weighing it in water ?
41. State how you would find the volume of a body using Archimedes' Principle, explaining carefully each step in your reasoning.
42. Why is it easier to swim in sea-water than in fresh water ?
43. Deduce the law concerning floating bodies from Archimedes' Principle.
44. Explain how to find the specific gravity of a liquid, using Archimedes' Principle.

DENSITY OF GASES

45. Describe an experiment which shows that air has weight.
46. How may the density of air be found ?
47. State how you would find the density of coal-gas.
48. How would you find approximately the weight of air in a room ?

PRESSURE

49. What principle is illustrated by Pascal's Vases ? Give other illustrations of it.
50. Distinguish between weight and pressure.

51. What is the unit of pressure (1) in the Metric System, (2) in the British System ?
52. How is the pressure at any point in a liquid measured ?
53. Will there be any difference in the pressure on the bottom of two reservoirs which hold equal quantities of water but which differ in area ?
54. Describe the U-tube method of finding the density of a liquid.
55. Is the pressure 100 feet below the surface of the sea the same as that 100 feet below the surface of an inland lake ? Why ?
56. How would you find the pressure of (1) the gas supply, (2) the water supply in the laboratory ?
57. Does water ever flow upwards ? Give examples and explain.

THE PRESSURE OF THE ATMOSPHERE

58. Explain the action of a fountain-pen filler or a self-filling pen.
59. Explain what happens when you drink lemonade using a straw.
60. Describe the Magdeburg Hemispheres experiment and explain it.
61. Draw a rough sketch of a suction pump and state what happens when the piston (1) descends, (2) ascends.
62. What is the greatest depth from which a suction pump can raise water ? Why is this the greatest depth ?
63. From what depth could a suction pump raise mercury?
64. How would you construct a simple barometer ?
65. What does a barometer measure ?
66. Why is water never used as a barometer liquid ?
67. Explain how it is that the barometer can foretell the probable state of the weather in the near future.
68. Relate how Pascal proved that it was really the pressure of the atmosphere that sustained the mercury in the Torricellian experiment.
69. If a barometer is taken down a mine will the height of the mercury change ? Why ?
70. What is a vacuum ? How may a vacuum be produced ?

71. What is the pressure of the air in lbs. per square inch? How is it that we do not feel this pressure?
72. What instrument does an airman use to indicate his height? State briefly the principle of the instrument.
73. What instrument is used to give a continuous record of the changes of atmospheric pressure? How does it work?

BOYLE'S LAW

74. Give an example of the fact that a gas can be compressed, that is, can be made to occupy a smaller space.
75. State Boyle's Law.
76. Draw a sketch of the apparatus you would use to verify Boyle's Law, and explain how you would proceed.
77. If the pressure on a certain quantity of air is doubled, how will the volume be affected? How will the density be affected?
78. If a barometer is taken up a hill it falls 1 inch for the first 900 feet of ascent, but less than 1 inch for the next 900 feet. Explain this.
79. If the mercury in a barometer fell 1 inch for every 900 feet of ascent, at what height would the pressure become zero?
80. How does a pop-gun work?
81. A toy balloon, tied at the mouth so that it contains only a few cubic centimetres of air, is placed under the receiver of an air-pump, and the air slowly pumped out of the receiver. Describe and explain what happens.

THERMOMETERS

82. What do you understand by the word temperature?
83. What is the difference between a Fahrenheit and a Centigrade thermometer?
84. Describe the method of filling a thermometer tube with mercury, giving the reason for each step.
85. How are the fixed points of a thermometer determined?
86. Give the approximate temperature (C. or F.) of (1) a comfortably-heated room, (2) a cold but not frosty day, (3) a hot bath, (4) the water in the boiler of a steam engine, (5) the healthy human body.

87. What were the objections to Galileo's thermometer ?
88. How was the zero of Fahrenheit's thermometer fixed ?

EXPANSION

89. Describe an experiment which shows that a solid expands when it is heated.
90. Give some everyday examples of expansion due to heat.
91. What is meant by the statement that the coefficient of expansion of steel is 0·000012 ?
92. Why must a wire fence erected in summer not be strung too tightly ?
93. Describe an experiment which shows that a liquid expands when it is heated. In what instrument is this fact made use of ?
94. Distinguish between the real and the apparent expansion of a liquid.
95. If ice is just beginning to form on the surface of a pond will the temperature of the water at the bottom be the same as, or different from, the temperature of the water at the surface ? Why ?
96. Describe the changes in volume that take place when water at 0° C. is heated to 10° C.
97. The unit of weight is the weight of 1 c.c. of water. What condition is made as to the temperature of the water ? Why ?
98. How would you show that a gas expands when it is heated ?
99. Contrast the expansion of gases with that of liquids.
100. What is meant by the coefficient of expansion of a gas ?
101. State Charles's Law.
102. State the law connecting the volume, temperature, and pressure of a gas.
103. What is meant by Absolute Zero ?
104. What words do the letters N.T.P. stand for ? What numbers do they stand for ?

TRANSMISSION OF HEAT

105. Name the three methods of transmitting heat, and state the essential features of each.

106. How would you show that copper conducts heat better than glass ?
107. Give some examples of the everyday use of bad conductors of heat.
108. Why does an iron gate feel colder than a wooden one on a frosty day ?
109. A piece of wire gauze is lowered on a gas flame. Describe and explain what happens.
110. State the principle of the miner's safety lamp, explaining how it prevents explosions in a mine.
111. Will the temperature of water rise more quickly when it is heated at the top or at the bottom ? Why ?
112. How is it that flannel keeps ice cold and also keeps people warm ?
113. Explain how a thermos flask keeps liquids warm ?
114. Why does warm air rise ?
115. How is a room ventilated ?
116. How does the heat from a furnace situated in the basement of a building heated by hot water pipes reach the top storey ?
117. Why do people who live in hot countries generally dress in white ?
118. How is it that it is cool in the shade ?

CHANGE OF STATE

119. What do you understand by the term " melting-point " ?
120. Does sea-water freeze at the same temperature as fresh water ?
121. Why do water pipes often burst during frost ? What is sometimes done to prevent pipes freezing ?
122. What is a calorie ?
123. The latent heat of water is 80. Explain this statement.
124. How would you find the latent heat of water ?
125. Is the boiling-point of water always 100° C. ? If not what alters it ?
126. The members of the Mount Everest Expedition of 1922 could not get a hot meal at a height of 27,000 feet. Why was this ?
127. What is the difference between boiling and evaporation ?

128. What is meant by the statement that the latent heat of steam is 536 ?
129. If a watch-glass containing some ether is placed on a wet bench, and a stream of air directed on to it, the glass will freeze to the bench. Why ?
130. Why is a burn from steam more severe than a burn from boiling water ?

SPECIFIC HEAT

131. The specific heat of copper is nearly 0·1. What does this mean ?
132. How would you find the specific heat of (1) a solid, (2) a liquid ?
133. Mention some of the effects of the high specific heat of water.
134. Why is the climate of an island different from the climate of those parts of a large continent which are in the same latitude as the island ?
135. How is it that the low specific heat of mercury is an advantage when mercury is used in a thermometer ?

NUMERICAL EXERCISES

VOLUME

1. Find the volume of a rectangular block of wood 4 inches long, 3 inches broad, and 2 inches high.
2. What is the volume of a rectangular block of steel 5 cm. long, 4 cm. broad, and 2·5 cm. high ?
3. 100 lead pellets are dropped into a measuring jar containing 40 c.c. of water, and the level of the water rises to 46 c.c. What is the average volume of one pellet ?
4. If 100 lead pellets, the average volume of each being 0·05 c.c., are dropped into a measuring jar containing 60 c.c. of water, what will be the reading on the jar ?
5. If the pellets in the previous question were dropped into a burette containing water, and the reading before the pellets were put in was 22·3 c.c., what will be the new reading ?
6. A cube whose edge is 2 cm. is lowered into a measuring jar containing 43 c.c. of water. What is the reading on the jar ?
7. A tin box is 23·5 cm. long, 12·4 cm. broad, and 10 cm. deep. Find the capacity of the box (1) in c.c., (2) in litres.
8. A piece of wood is attached to a lead cube whose edge is 3 cm. and then lowered into a Eureka can full of water. If 44 c.c. of water overflow, what is the volume of the piece of wood ?

DENSITY

9. What is the density of brass if 6 c.c. of brass weigh 51 grams ?

10. What is the density of turpentine if 100 c.c. weigh 87 grams ?
11. What is the density of aluminium if a rectangular block of it measuring 3 cm. by 2 cm. by 1·5 cm. weighs 23·4 grams ?
12. An empty beaker weighs 16·2 grams. After 10 c.c. of turpentine have been added, the weight is 24·7 grams. What is the density of turpentine ?
13. Thirty lead pellets each weighing 0·684 grams are dropped into a burette containing water reading 41·3 c.c. If the new reading is 39·5 c.c. find the density of lead.

Find the weight of :—

14. 27·5 c.c. of lead of density 11·4 grams per c.c.
15. 14·2 c.c. of sulphur of density 2·07 grams per c.c.
16. 24 c.c. of benzine of density 0·88 gram per c.c.

Find the volume of :—

17. 27·5 grams of lead.
18. 14·2 grams of sulphur.
19. 24 grams of benzine.
20. If 1000 c.c. of pure water are added to 6300 c.c. of sea-water (density 1·025 grams per c.c.), find the density of the mixture.
21. Find the density of a mixture of 42·3 c.c. of water and 15 c.c. of ammonia (density 0·88 gram per c.c.).
22. A 50 c.c. bottle weighs 50 grams when filled with ammonia (density 0·88 gram per c.c.). Calculate its weight when empty.

FLOATING BODIES

23. A rectangular block measures 3 cm. by 2 cm. by 1·5 cm. and weighs 7 grams. What is its density ? Will it float or sink in water ?
24. A rectangular block 4 cm. by 2·5 cm. by 2 cm. weighs 22 grams. What is its density ? Will it float or sink in water ?
25. A cork weighs 2 grams and has a volume of 8 c.c. How much water will it displace when floating ?
26. A piece of wood displaces 4 c.c. of water when floating and 10 c.c. when completely immersed. What is its density ?

27. A wooden rod displaces 12 c.c. when floating in water and 16 c.c. when floating in another liquid. What is the density of the liquid ?
28. A metal cube whose edge is 2 cm. is attached to a cork weighing 2·5 grams and lowered into a Eureka can full of water. If 18 c.c. of water overflow, what is the density of the cork ?
29. A loaded test-tube weighs 17 grams and floats in 38 c.c. of water contained in a measuring jar. What is the reading on the jar ?
30. A wooden rod floats in 36 c.c. of water in a measuring jar and the reading is 48 c.c. What is the weight of the rod ?
31. A loaded test-tube displaces 11·2 c.c. when floating in water and 10·9 c.c. when floating in milk. What is the density of milk ?
32. Find the weight of a floating body which displaces 25 c.c. of a liquid whose density is 1·026 grams per c.c.
33. A wooden rod is floated in a measuring jar containing 150 c.c. of water and the reading is 202·5 c.c. If the rod is pushed down till covered with water, the reading is 225 c.c. What is the density of the rod ?

SPECIFIC GRAVITY

34. A rectangular wooden block measures 5 cm. by 4 cm. by 3 cm. and weighs 45 grams. What weight of water will it displace when completely immersed in water ? What is its specific gravity ?
35. A specific gravity bottle weighs 12 grams when empty, 62 grams when full of water, and 67 grams when full of blue vitriol. What is the specific gravity of blue vitriol ?
36. If a gallon of water weighs 10 lb. what is the weight of a gallon of mercury, the specific gravity of mercury being 13·6 ?
37. What weight of water can a cubical vessel of edge 5 cm. hold ? What weight of sulphuric acid (S.G. 1·84) will the same vessel hold ?
38. An empty flask weighs 34·5 grams, filled with water it weighs 134·5 grams, and filled with alcohol it weighs 126·1 grams. Find the specific gravity of alcohol.

39. A specific gravity bottle full of water weighs 58·92 grams. Some lead pellets weighing 34·26 grams are dropped into the bottle and the weight of the bottle and its contents is then 90·17 grams. What is the specific gravity of lead ?

ARCHIMEDES' PRINCIPLE

40. What weight of water will be displaced by a stone weighing 15·6 grams in air and 12·4 grams in water ?
41. A piece of zinc weighs 24·38 grams in air and 20·95 grams in water. What is the density of zinc ?
42. A piece of aluminium weighs 12·19 grams in air and 7·50 grams in water. What is the specific gravity of aluminium ?
43. A glass stopper weighs 13·29 grams in air, 8·86 grams in water, and 9·44 grams in turpentine. Find (1) the specific gravity of glass, (2) the specific gravity of turpentine.
44. A cork weighing 0·5 gram is tied to a piece of lead which weighs 10 grams in air and 9·12 grams in water, and together they weigh 7·55 grams in water. What is the specific gravity of the cork ?

DENSITY OF GASES

45. A 400 c.c. flask full of air weighs 162·45 grams. When the air has been extracted by means of an air-pump the weight is 161·97 grams. Find the density of air.
46. A small quantity of water is poured into a flask and boiled till the air has been driven out and a clip is put on. The flask after cooling weighs 143·26 grams. Air is admitted and the weight is then 143·67 grams. If there are 36 c.c. of water left in the flask and the capacity of the flask is 372 c.c., find the density of air.
47. Using the same apparatus as in the previous question, 42 c.c. of water were left in the flask, and coal-gas was admitted instead of air. The weights before and after admitting the gas were 149·24 grams and 149·43 grams respectively. What is the density of coal-gas ?
48. A room is 10 metres long, 8 metres broad, and 6 metres

high. Find the weight of air in the room in cwts. (1 litre of air weighs 1·29 grams; 1 kilogram = 2·2 lb.).

49. A 100 c.c. flask full of air weighs 61·74 grams. If a litre of air weighs 1·3 grams, what is the weight of air in the flask?

50. If the flask in the previous question is filled with another gas and then weighs 61·82 grams, what is the weight of a litre of this gas?

51. If a litre of a gas whose density is 1·44 grams per litre is mixed with 4 litres of a gas whose density is 1·26 grams per litre, what is the density of the mixture?

PRESSURE IN LIQUIDS

52. What is the pressure at a depth of 15 cm. (*a*) in water, (*b*) in mercury (density 13·6 grams per c.c.).

53. Mercury is poured into a long tube till it stands 30 inches high. Find the pressure on the bottom of the tube. (S.G. of mercury = 13·6; 1 cub. foot of water weighs 62·5 lb.).

54. Water is poured into one limb of a U-tube and turpentine is poured on top of it. If the free surfaces of the water and the turpentine are 14·7 cm. and 16·7 cm. respectively above the bench and the common surface is 4·5 cm. above the bench, what is the density of turpentine?

55. Mercury fills the bend of a U-tube. Water is poured into one limb and blue vitriol solution into the other till the mercury surfaces are at the same level. If the water and blue vitriol columns are 13·5 cm. and 12·5 cm. high respectively, find the density of blue vitriol.

56. Mercury fills the bend of a U-tube. Water is poured into one limb till it forms a column 20·4 cm. high. How far will the mercury rise in the other limb?

57. What will be the height of a column of salt water (density 1·02 grams per c.c.) which will bring the mercury surfaces of the previous question to the same level again?

58. What is the pressure at a depth of half a mile below the surface of an inland lake? If the specific gravity of sea-water is 1·03, what is the pressure at a depth of half a mile below the surface of the sea (1 cub. foot of water weighs 62·5 lb.).

THE BAROMETER

59. The normal height of the barometer is 30 inches, which corresponds to a pressure of about 14·7 lb. per sq. in. What will be the pressure at a place where the height of the barometer is (1) 20 inches, (2) 25 inches ?
60. What is the atmospheric pressure in grams per sq. cm. when the barometer stands 75 cm. high ?
61. On the top of a hill the barometric height is 70 cm. What is the atmospheric pressure in grams per sq. cm. ? If 1 gram = 0·0022 lb. and 1 cm. = 0·4 inch, what is the pressure in lbs. per sq. in ?
62. What would be the height of a water barometer on a day when the mercury barometer stands at 30 inches ?
63. Air is allowed to enter a barometer tube full of mercury until the mercury stands 56 cm. high. What is the pressure (in grams per sq. cm.) of the air in the tube if the barometric height is 76 cm. ?
64. The Mount Everest Expedition of 1922 reached a height of about 27,000 feet, and the barometric reading at that height was $10\frac{1}{2}$ inches. What was the pressure in lbs. per sq. in. ?

BOYLE'S LAW

65. If the volume of a gas at normal pressure is 20 cub. in., what will be its volume under a pressure of 20 inches of mercury ?
66. If the volume of a gas at normal pressure is 20 cub. in., what will be its pressure when the volume changes to 15 cub. in.
67. 1000 c.c. of a gas are measured under a pressure of 80 cm. of mercury. What would be the volume under normal pressure ?
68. An expansible balloon which on the ground contains 1000 cubic metres of gas at 75 cm. pressure rises till the barometer records 50 cm. If the volume were not affected by the coldness of the upper air, by how much would the balloon expand ?
69. A bubble of air lying at the bottom of a pond 9 feet deep has a volume of 3·4 cub. in. If it rises to the surface what will be its volume as it emerges ?

70. A bubble of gas has a volume of 0·85 cub. in. when lying at the bottom of a pond. If its volume increases by 0·65 cub. in. when it rises to the surface, calculate the depth of the pond.

71. The volume of air enclosed in a Boyle's Law tube is 19 c.c. The barometric height is normal, and the difference in level of the mercury in the two limbs of the tube is 34 cm. What would be the volume of the air if the mercury were at the same level in both limbs ?

THERMOMETERS

72. What are the readings on the Fahrenheit thermometer corresponding to the following readings on the Centigrade thermometer : (1) 0° C., (2) 15° C., (3) 50° C., (4) 80° C., (5) 100° C., (6) −20° C., (7) −40° C., (8) 120° C.

73. What are the readings on the Centigrade thermometer corresponding to the following readings on the Fahrenheit thermometer : (1) 41° F., (2) 68° F., (3) 194° F., (4) 203° F., (5) 23° F., (6) −13° F., (7) −40° F., (8) 230° F.

74. What temperature is represented by the same number on both thermometers ?

EXPANSION OF SOLIDS AND LIQUIDS

75. The telegraph poles along a certain road are 100 yards apart. Assuming that the wires are perfectly horizontal at −20° C., what will be the length of wire between each two poles on a day when the temperature is 40° C. ? (coefficient of expansion of copper = 0·000017).

76. In the ball and ring experiment the diameter of the ball at 20° C. is 4 cm. What will be its diameter after being heated to a temperature of 520° C. (coefficient of expansion of brass = 0·000019).

77. An aluminium wire is 1000 cm. long at 15° C. and 1001·95 cm. long at 100° C. What is the coefficient of expansion of aluminium ?

78. A 50 c.c. bottle is filled with mercury at 10° C. and is

then suspended in boiling water at 100° C. What volume of mercury will overflow (coefficient of expansion of mercury = 0·00018)? What weight of mercury will overflow?

79. A flask fitted with a rubber stopper through which passes a long glass tube holds 500 c.c. of turpentine at 10° C. If each inch of the tube holds 0·21 c.c. and the flask is placed in a vessel of water at 50° C., how high will the liquid rise in the tube (coefficient of expansion of turpentine = 0·000105)?

80. A graduated vessel containing alcohol reads 120 c.c. at 10° C. and 120·6 c.c. at 60° C. What is the coefficient of expansion of alcohol?

EXPANSION OF GASES

(At Constant Pressure)

81. The volume of a gas at 0° C. is 27·3 c.c. and at 27° C. it is 30 c.c. What is its coefficient of expansion?

82. A certain quantity of air occupies 600 c.c. at 0° C. What will be its volume at 91° C.?

83. A gas is measured at 18° C. and found to occupy 120 c.c. What would be its volume at −5° C.?

84. 100 c.c. of a gas are measured at 10° C. How many c.c. will it occupy at (1) 20° C., (2) 15° C., (3) 0° C., (4) −15° C.?

85. A room contains 300 cubic metres of air. How much air will escape from the room if it is uniformly warmed from 15° C. to 16° C.?

86. 100 c.c. of a gas are measured at 10° C. The gas is heated till its volume becomes 150 c.c. What is now its temperature?

87. A gas occupies 15·5 cub. feet at 99° C. What will be its volume at normal (or standard) temperature?

THE GAS LAWS

88. A litre of gas is measured at 15° C. under a pressure of 74 cm. of mercury. What would be its volume at N. (or S.) T.P.?

89. An air thermometer contains 10 c.c. of air at 3° C. and 76 cm. pressure. What will be its volume at 10° C. and 80 cm. pressure ?

90. A cubic metre of air at N.T.P. rises from the surface of the earth till the temperature is −50° C. and the pressure 20 cm. of mercury. What will be its volume at this height ?

91. If the pressure on a gas is doubled and at the same time the temperature is increased from 0° C. to 91° C., how will the volume be affected ?

SPECIFIC HEAT

How many calories are required to raise the temperature of :—

92. 25 grams of water from 10° C. to 50° C. ?

93. 25 grams of copper (specific heat 0·09) from 10° C. to 50° C. ?

94. 25 grams of aluminium (specific heat 0·22) from 10° C. to 50° C. ?

95. 25 grams of mercury (specific heat 0·033) from 10° C. to 50° C. ?

What would be the effect of giving 100 calories to :—

96. 20 grams of water at 10° C. ?

97. 20 grams of copper at 10° C. ?

98. 20 grams of aluminium at 10° C.

99. 20 grams of mercury at 10° C.

100. A copper calorimeter weighs 40 grams and contains 50 grams of water at 10° C. Some brass tacks at 100° C., weighing 20 grams, are mixed with the water, and the resulting temperature is 13° C. Find the specific heat of brass, the specific heat of copper being 0·09.

101. Find the final temperature when 50 grams of turpentine (specific heat 0·41) at 10° C. are mixed with 40 grams of tin (specific heat 0·055) at 80° C.

LATENT HEAT

102. If 1000 calories are given to 10 grams of ice at 0° C. and the temperature of the water obtained is 20° C., find the latent heat of water.

103. If a further 2408 calories are given to the 10 grams of water at 20° C., raising it to boiling-point and changing 3 grams into steam, find the latent heat of steam.

What will be the effect of giving :—

104. 1080 calories to 12 grams of ice at 0° C. ?

105. 1080 calories to 12 grams of water at 0° C. ?

106. 1080 calories to 12 grams of water at 100° C. ?

107. 4840 calories to 12 grams of ice at 0° C. ?

ANSWERS TO NUMERICAL EXERCISES

1. 24 cub. in.
2. 50 c.c.
3. 0·06 c.c.
4. 65 c.c.
5. 17·3 c.c.
6. 51 c.c.
7. (1) 2914 c.c.
   (2) 2·914 litres.
8. 17 c.c.
9. 8·5 gm. per c.c.
10. 0·87 gm. per c.c.
11. 2·6 gm. per c.c.
12. 0·85 gm. per c.c.
13. 11·4 gm. per c.c.
14. 313·5 gm.
15. 29·39 gm.
16. 21·12 gm.
17. 2·41 c.c.
18. 6·86 c.c.
19. 27·27 c.c.
20. 1·022 gm. per c.c.
21. 0·97 gm. per c.c.
22. 6 gm.
23. 0·78 gm. per c.c.
    It will float.
24. 1·1 gm. per c.c.
    It will sink.
25. 2 gm.
26. 0·25 gm. per c.c.
27. 0·75 gm. per c.c.
28. 0·25 gm. per c.c.
29. 53 c.c.
30. 12 gm.
31. 1·028 gm. per c.c.
32. 25·65 gm.
33. 0·7 gm. per c.c.
34. 60 gm.
    0·75.
35. 1·1.
36. 136 lb.
37. 125 gm.
    230 gm.
38. 0·916.
39. 11·38.
40. 3·2 gm.
41. 7·1 gm. per c.c.
42. 2·6.
43. 3.
    0·87.
44. 0·24.
45. 1·2 gm. per lit.
46. 1·2 gm. per lit.
47. 0·58 gm. per lit.
48. 12·1 cwts.
49. 0·13 gm.
50. 2·1 gm. per lit.
51. 1·296 gm. per lit.
52. (*a*) 15 gm. per sq. cm.
    (*b*) 204 gm. per sq. cm.
53. 14·7 lb. per sq. in.

54. 0·84 gm. per c.c.
55. 1·08 gm. per c.c.
56. 0·75 cm.
57. 20 cm.
 73·7 tons per sq. ft.
58. 76 tons per sq. ft. (nearly).
59. (1) 9·8 lb. per sq. in.
 (2) 12·25 lb. per sq. in.
60. 1020.
61. 952 gm. per sq. cm.
 13·09 lb. per sq. in.
62. 34 ft.
63. 272 gm. per sq. cm.
64. 5·16 lb. per sq. in.
65. 30 cub. in.
66. 40 in.
67. 1052·6 c.c.
68. 500 c.M.
69. 4·3 cub. in.
70. 26 ft.
71. 27·5 c.c.
72. (1) 32° F.
 (2) 59° F.
 (3) 122° F.
 (4) 176° F.
 (5) 212° F.
 (6) −4° F.
 (7) −40° F.
 (8) 248° F.
73. (1) 5° C.
 (2) 20° C.
 (3) 90° C.
 (4) 95° C.
 (5) −5° C.
 (6) −25° C.
 (7) −40° C.
 (8) 110° C.
74. −40°.
75. 100·1 yds.
76. 4·038 cm.
77. 0·000023.
78. 0·81 c.c.
 11·016 gm.
79. 10 cm.
80. 0·0001.
81. $\frac{1}{273}$.
82. 800 c.c.
83. 110·5 c.c.
84. (1) 103·5 c.c.
 (2) 101·8 c.c.
 (3) 96·5 c.c.
 (4) 91·2 c.c.
85. 1·04 c.M.
86. 151°·5 C.
87. $11\frac{3}{5}$ cub. ft.
88 922·97 c.c.
89. 9·74 c.c.
90. 3·1 c.M.
91. Volume is reduced by $\frac{1}{3}$.
92. 1000.
93. 90.
94. 220.
95. 33.
96. Temp. raised to 15° C.
97. Temp. raised to 65°·6 C.
98. Temp raised to 32°·7 C.
99. Temp. raised to 161°·5 C.
100. 0·092.
101. 16°·8 C.
102. 80.
103. 536.
104. Ice melted and temp. raised to 10° C.
105. Temp. raised to 90° C.
106. 2 gm. changed into steam at 100° C.
107. Ice melted, temp. raised to 100° C. and 5 gm. changed to steam.